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Health effects literature primarily related to inhalation exposures to ammonia was collected, evaluated, tabulated, and summarized. Approximately 200 documents were collected from computerized and manual literature searches covering the period 1886-1981. Pharmacologists and an M.D. epidemiologist rated the documents according to their applicability to the study and their methodology. The approximately 50 documents considered useful for deriving a range of concern for human exposure to ammonia from automotive emissions were tabulated. The 50 pages of tables detail the results of acute, repeated dose, and chronic testing of bats, mice, rats, guinea pigs, chickens, rabbits, cats, monkeys, dogs, turkeys, swine, and humans as well as human occupational and accidental studies. Most of the documents evaluated are described in an annotated bibliography.

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AMMONIA HEALTH EFFECTS
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September 17, 1981

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For

Emission Control Technology Division
Office of Mobile Source Air Pollution Control
U.S. Environmental Protection Agency
2565 Plymouth Road
Ann Arbor, Michigan 48105

Attn: Robert J. Garbe

PREFACE

This report on health effects of ammonia was prepared by Midwest Research Institute (MRI) as Task No. 3 under Contract No. 68-03-2928, "Health Effects Support for the Emission Control Technology Division" for the U.S. Environmental Protection Agency.

Health effects literature primarily related to inhalation exposures to ammonia has been collected, evaluated, tabulated, and summarized so that this report can be used to derive a range of concern for human exposure to vehicular atmospheric emissions of ammonia.

Task activities were coordinated by the project leader, Mrs. Bonnie L. Carson, Senior Chemist, and task leader, Ms. Cecily M. Beall, Assistant Scientist. Documents were rated and summarized by senior pharmacologist Harry V. Ellis III, of MRI, and epidemiologist Larry H. Baker, M.D., MRI consultant, who is an Associate Professor in the Department of Community Health at the University of Kansas Medical Center. Data were tabulated by Ms. Beall; Joy L. McCann, Assistant Scientist; and Ms. Carol Foret, Literature Aide. Ms. Beall and Mrs. Carson contributed to the annotated bibliography. This study was performed under the general supervision of Dr. Edward W. Lawless, Head, Chemical Impact Assessment Section.

Mr. Robert J. Garbe was the project monitor for the Emission Control Technology Division, U.S. Environmental Protection Agency, and Ms. Colleen DeMeyer served as Branch Technical Representative.

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CONTENTS

Page

Preface iii
Figures vi
Tables vi

Summary 1
    Animal studies 1
    Human studies 6
    Other possible exposures to ammonia 9
    Recommended range of concern 10
I. Introduction 11
II. Bioassay 15
III. Experimental Animal Inhalation Exposures 17
IV. Experimental Human Inhalation Exposures 55
V. Epidemiology 63
    Occupational exposures 63
    Accidental exposures 63

Bibliography 73

FIGURES

Number Page

I-1 Form for report rating 12

TABLES

Number Page

S-1 Summary of Experimental Animal Exposure to NH_3 2
S-2 Summary of Human Experimental Exposure to NH_3. 7
S-3 Summary of Occupational Exposure to NH_3. 8
II-1 Bioassays. 16
III-1 Bats--Acute Experimental Exposure to NH_3 18
III-2 Mice--Acute Experimental Exposure to NH_3 19
III-3 Mice--Repeated Dose Experimental Exposure to NH_3 20
III-4 Rats--Acute Experimental Exposure to NH_3 21
III-5 Rats--Repeated Dose Experimental Exposure to NH_3 22
III-6 Rats--Chronic Experimental Exposure to NH_3 26
III-7 Guinea Pigs--Acute Experimental Exposure to NH_3. 29
III-8 Guinea Pigs--Repeated Dose Experimental Exposure to NH_3. . 30
III-9 Guinea Pigs--Chronic Experimental Exposure to NH_3. 31
III-10 Chickens--Acute Experimental Exposure to NH_3 32
III-11 Chickens--Repeated Dose Experimental Exposure to NH_3 . . . 33
III-12 Rabbits--Acute Experimental Exposure to NH_3. 39
III-13 Rabbits--Repeated Dose Experimental Exposure to NH_3. . . . 42
III-14 Rabbits--Chronic Experimental Exposure to NH_3. 43
III-15 Cats--Acute Experimental Exposure to NH_3 44
III-16 Monkeys--Repeated Dose Experimental Exposure to NH_3. . . . 45
III-17 Monkeys--Chronic Experimental Exposure to NH_3. 46
III-18 Dogs--Repeated Dose Experimental Exposure to NH_3 47
III-19 Dogs--Chronic Experimental Exposure to NH_3 48
III-20 Turkeys--Repeated Dose Experimental Exposure to NH_3. . . . 49
III-21 Swine--Acute Experimental Exposure to NH_3. 51
III-22 Swine--Repeated Dose Experimental Exposure to NH_3. 52
IV-1 Humans--Acute Experimental Inhalation Exposure to NH_3. . . 56
IV-2 Humans--Repeated Dose Experimental Inhalation Exposure to NH_3 60
V-1 Studies of Occupational Exposure to Ammonia. 64
V-2 Humans--Studies of Accidental Exposures to Ammonia 68

SUMMARY

The goal of this task is to compile and evaluate data from the literature on the health effects of inhalation exposure to NH_3. The results will assist the Emission Control Technology Division (ECTD) of the U.S. Environmental Protection Agency in establishing a range of concern for NH_3 in exhausts from vehicles equipped with emission control devices (e.g., catalytic converters) and in providing guidance to automobile manufacturers. The exposures of particular concern are those that may occur in traffic jams, in public parking garages, in home and repair shop garages, in tunnels, and in other situations where little dilution of the exhaust is expected before inhalation. Most of the report (as directed by ECTD) is in the form of tables based on the literature reviewed. Data from exposures at higher levels than of primary concern are included because strictly relevant information was scarce and these related data might prove helpful in assessing health effects at lower levels.

Documents on inhalation effects of NH_3 identified from manual and computerized literature searches were rated in a two-step process by the project pharmacologist and epidemiologist. First, the document received an A, B, C, D rating according to its applicability for deriving a range of concern for NH_3 in automobile emissions. Second, if the paper was not a low-rated foreign-language document,* a theoretical paper, a review, or a nontoxicology experimental paper, it received a numerical score based on itemized features that should be present in an ideal report.

All A- or B-rated documents were tabulated. Occupational documents receiving a C or D rating because of the possible presence of confounding factors were included if the exposure to NH_3 was confirmed and of a low level.

ANIMAL STUDIES

A summary of the animal data for exposures to $\leq$ 36 mg NH_3/m^3 is given in Table S-1. The complete data are given in the tables in Section III.

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* Most foreign-language articles rated C and D were usually not translated. Each foreign-language abstract tentatively rated A or B from an English-language abstract or brief examination of the paper was translated in sufficient degree to judge the experimental design and details. These papers were numerically scored from the translation.

TABLE S-1. SUMMARY OF EXPERIMENTAL ANIMAL EXPOSURE TO NH_3

Level of Exposure (mg/m^3)	Exposure Time	Species	Effects								Comments
			Lung lesions	Changes in lung function	Changes in respiratory tract	Changes in other organs	Eye irritation	Decreased body weight gain	Decreased food consumption	Increased microbial infection *	
36-36.7	48 h	CKN								++	
	4 wk or 33 d	CKN						+	+		
	3 h	RBT		++							
	2 d	TRK									NOEL
	12 d	TRK	++					++			Anorexia
	2 h	PIG			+					++	Bacterial exposure prior to NH_3 exposure.
	19 or 71 d	PIG					++				Decreased body weight gain when also exposed to 300 mg/m^3 dust.
	6 wk	GPG	++			++					
	52 d	RAT									NOEL at 22°C; slight effect at 10°C.
	35 d	RAT	++		++						Concurrent bacterial exposure.
7.2-32.4	4 wk	CKN									NOEL, compared to more exposed groups.
14.4-21.6	10 wk	TRK			++						Effect probably due to dust at 0.1-0.4 mg/ft^3.
	52 d or 7 mo	RAT				+		+			Slight initial decrease in reflex response; decreased vitamin levels in some organs; biochemical changes in blood and urine.
	49 d	RAT	++			++					Concurrent bacterial exposure.
14.4	42 d	GPG	++D								
	42 d	MUS	++D								
	6 d	TRK			++i						
	72 h	CKN								++	High level viral exposure following NH_3 exposure.
	4-12 wk	CKN	++		+i						
0-8.6	5 wk	PIG									Feed consumption above groups exposed to higher levels.
	4 mo	RAT			++					++	Concurrent bacterial exposure.
	12 wk	TRK			++						Only with concurrent high levels of dust (0.6-1.0 mg/ft^3).
2-3	84 d or 4 mo	RAT									NOEL (even following concurrent bacterial exposure) other than slight inhibition of the blood redox function in the first mo.
0.2	84 d	RAT									NOEL

* In comparison to control animals given the same microbial exposure.
i Initial response, at early stages only.
D Delayed response.
+ Slight symptoms.
++ Moderate symptoms.

Acute Animal Studies

Among the rodent studies, Lehmann (1886) found minor, reversible irritation ("annoyance") in rats and guinea pigs given the lowest reported dose, about 400 mg NH_3/m^3 for 4 h. The one mouse study is not contradictory. Lehmann (1886) found that higher doses (about 800 mg/m^3 and up) produce decreased respiration, secretions, and other such obvious symptoms of irritation. At extreme doses (lethal to near lethal) of several thousand milligrams per cubic meter, the lung reaction included hyperemia as well as edema.

Both Lehmann (1886) and Richard et al. (1978b) found similar thresholds in rabbits. In Richard et al.'s study, curarized rabbit preparations showed bradycardia, arrhythmias, and extrasystoles at the toxic levels of NH_3.

Lehmann (1886) reported that the same minimum dose in cats (about 400 mg/m^3) produced reversible irritation, with increased effects, especially secretions, at higher doses. Dodd and Gross (1980) made pulmonary function tests on cats given 720 mg/m^3 for 10 min. This level was quite toxic, with slow recovery. One cat of 20 died of bronchopneumonia, presumably influenced by the lung damage caused by NH_3.

In other species, Charles and Payne (1966a) found a decrease in respiration rate in some chickens given 72 mg NH_3/m^3 for an unspecified period and a small increase in blood pH in hens given 54 mg/m^3. In a test of susceptibility to infection, Drummond et al. (1978) found that swine given 36 mg/m^3 of ammonia had increased retention of viable aerosolized bacteria and increased pulmonary weight, but no apparent gross or histopathologic lesions. These results correlate well with the report of bronchopneumonia in the cat.

Repeated Dose Animal Studies

Anderson et al. (1964) found that 4-wk exposure of mice and of guinea pigs to 14.4 mg NH_3/m^3 had no effect, but 6-wk exposure produced lung lesions (hyperemia, edema, congestion). Anderson et al. (1964) also found that if guinea pigs were exposed to 36 mg/m^3 continuously for 6 wk, they developed similar but more severe lung lesions, plus congestion in the liver and spleen. In sharp contrast, Coon et al. (1970) found that 155 mg/m^3 given to guinea pigs 40 h/wk for 6 wk or 40 mg/m^3 given to guinea pigs continuously for 114 d was nontoxic. The strain of guinea pig used in Anderson et al. (1964) was not given, but these differences may be due to varying sensitivity between strains. Exposure to 770 mg/m^3 8 h/d for 6 wk did cause lung lesions (Coon et al., 1970). These studies imply a fairly good "C x t effect" (concentration times time is constant for similar effects).

Many relevant studies have been made with rats. In Russian studies aimed at determining a maximum permissible concentration (Saifutdinov, 1966 and 1968), 12-wk exposures to 0.2 mg/m^3 had no effects; exposure to 2 mg/m^3 had negligible effects (inhibition of blood redox function in the first few weeks only); and exposure to 20 mg/m^3 had some minor effects (inhibition of brain cholinesterase, increased urinary coproporphyrins), which disappeared after exposure ceased. The observed effects are minor and of questionable toxicological importance, further marred by a lack of experimental detail.

In more usual types of studies, Stolpe and Sedlag (1976) found that a 52-d exposure to 21.6, 36, or 65 mg/m^3 did not affect rats dosed at normal temperature, whereas the 36 and 65 mg/m^3 levels were mildly toxic (decreased weight gain with partial recovery) to rats kept at 10°C. Broderson et al. (1976) found some histopathologic changes in respiratory and olfactory epithelia of rats exposed to 108 mg/m^3 for 75 d or to 180 mg/m^3 for 35 d. Coon et al. (1970) found no effects in rats exposed to 155 mg/m^3 40 h/wk for 6 wk, but severe effects (including death of two-thirds of the rats) in those exposed to 455 mg/m^3; no histopathology was done. Richard et al. (1978a) found that 360 mg/m^3 for 5 d or more was toxic, with respiratory lesions appearing after 3 wk.

Broderson et al. (1976) exposed rats to varying levels of NH_3 for 5 wk, and challenged them with an intranasal inoculation of infectious bacteria on day 7. While even the lowest dose (18 mg/m^3) increased the infection severity, there were increasingly severe effects at each level up to the highest used (180 mg/m^3).

Only two studies reported results with rabbits. Mayan and Merilan (1972) found that both levels used (36 and 72 mg/m^3) decreased the respiration rate every time the brief (2.5-3 h) exposure was repeated (at unstated intervals). Coon et al. (1970) exposed rabbits 40 h/wk for 6 wk. His higher dose of 770 mg/m^3 caused dyspnea and lacrimation during the first few days only. Repeated exposure to that dose beyond the first week or to 155 mg/m^3 had no effects. Coon et al. (1970) also tested dogs and monkeys with the same protocol. Results in beagle dogs were identical to those in rabbits. The squirrel monkeys were apparently unaffected; one low-dose monkey had focal pneumonitis, but this is not unusual.

Because closed, air-conditioned livestock and poultry facilities are widely available, many studies have involved swine and poultry. Most of these involved combined exposures (with manure gas, dust, and similar contaminants); but some studies do have useful, separate exposures. Stombaugh et al. (1969) found inconsistent, but probably negligible, effects in pigs exposed to 44 or 9 mg NH_3/m^3 for 5 wk. Higher levels (74 and 104 mg/m^3) decreased feed consumption and caused coughing and nasal, lacrimal, and oral secretions. The highest level (201 mg/m^3) was given to only one animal which exhibited severe irritation symptoms and convulsed after 36-h exposure, but recovered 7 h after exposure.

Curtis et al. (1975) found no consistent changes in pigs exposed to 36 mg NH_3/m^3 for 71 d or to that dose plus 2.8 mg H_2S/m^3 for 19 d or to that dose plus 10 mg dust/m^3 for 27 d. If the dust concentration was increased to 300 mg/m^3, weight gain decreased. Exposure to 54 mg NH_3/m^3 for 109 d without added dust had no adverse effects, indicating that the high dust levels gave reduced weight gain.

Doig and Willoughby (1971) found slight effects (conjunctivitis in the first or second week, upper respiratory tract epithelium reaction) in pigs exposed for 6 wk to 77 mg NH_3/m^3 alone or with ground corn dust (10.6 or 213 mg/m^3).

Anderson et al. (1964) found that exposure of chickens to 14.4 mg NH_3/m^3 for 24 h to 28 d caused a brief (up to 3 or 4 d) increase in mucus secretion, but no pathology or obvious discomfort. Exposure for 6 wk or longer produced hyperemic, dense lungs with congestion, edema, and hemorrhage. Valentine (1964) studied exposures of chickens at rather widely varying NH_3 levels, apparently without controls, and reported a dose-response curve. Decreased weight gain and, at sufficiently high doses, eye ulcerations were observed.

Charles and Payne (1966a) found mild, somewhat inconsistent, toxic effects in two groups of chickens exposed to 37 or 38 mg NH_3/m^3. Larger doses (56 and 72 mg/m^3) gave decreased feed consumption and weight gain in the later parts of the studies.

Anderson et al. (1964) did an interaction study in which chickens were exposed to NH_3 for 18 d and then given an aerosol of Newcastle disease virus. At the lowest NH_3 level studied (14.4 mg/m^3), the lower virus dose (3 ELD_{50}'s/liter for 3 min) was not affected by the pretreatment, while the higher virus dose (6 ELD_{50}'s/liter) infected all the pretreated birds and half of the controls. With pretreatment at 36 mg/m^3 and the higher virus dose, results were similar.

Anderson et al. (1964) found that turkeys exposed to 14.4 mg NH_3/m^3 for 6 d followed by 36 mg/m^3 for 2 d were unaffected. However, exposure to 36 mg/m^3 for 12 d did produce increasing lung effects (congestion, edema, hemorrhage) plus anorexia and decreased weight gain. Anderson et al. (1968) reported on studies with turkeys exposed to low (nontoxic) levels of NH_3 plus various levels of dust. The dust caused adverse effects, but no interaction between the NH_3 and dust was reported.

Chronic Studies in Animals

Coon et al. (1970) found that 114 d at 40 mg NH_3/m^3 and 90 d at 127 mg NH_3/m^3 had no adverse effect on rats. However, 90 d at 262 mg/m^3 caused some symptoms (nasal discharge in ∿ 25% of rats) while 470 mg/m^3 was lethal to most rats, with interstitial pneumonitis the main lesion. Mikhailuts et al. (1979) studied in rats the interaction of exposure for 35 h/wk for 4 mo to low levels of NH_3 with intranasal exposure to pathogenic bacteria. The low dose of 3 mg/m^3 had no effect, but the high dose of 6 mg/m^3 increased bacterial effects. Particularly significant were decreases in the usual protective effect of phagocytes.

Coon et al. (1970) found that guinea pigs were much like rats, although somewhat less sensitive, with no effects from 114 d at 40 mg/m^3 and some deaths from interstitial pneumonitis after 90 d at 470 mg/m^3. They found that rabbits were about as sensitive as guinea pigs (no deaths, but lung lesions in the three rabbits dosed at 470 mg/m^3 for 90 d); marked eye irritation was noted. Results in beagle dogs and squirrel monkeys followed the pattern: no adverse effects after 114 d at 40 mg/m^3, interstitial pneumonia and (in dogs) irritation, but no deaths, in the few animals given 470 mg/m^3 for 90 d.

HUMAN STUDIES

A summary of all the human experimental data is given in Table S-2, and of the occupational data in Table S-3.

Experimental Studies

A moderate number of experiments has been done on humans exposed to ammonia at various concentrations. The details of acute experimental inhalation exposure studies are given in Table IV-1, with repeated dose studies in Table IV-2.

The first observed effect at low levels of NH_3 appears to be odor perception. Reported threshold values vary considerably within studies and between studies. Sayfutdinov (1968) reported perception thresholds for 22 subjects varying from 0.45 to 1.0 mg/m^3. In contrast, Keplinger et al. (1973) found that one subject (of 10) could not detect 23 mg NH_3/m^3, although he could detect 33.7 mg/m^3. In a poorly controlled study, Mikhailov et al. (1969) found metabolic evidence of ammonia exposure (such as increases in urinary ammonia and urea) after 8-h exposure to 13 mg NH_3/m^3, but not after 3 mg/m^3. No adverse effects were reported; the alterations are within normal metabolic ranges.

The first adverse effect of NH_3 appears to be irritation of the nose and/or eyes. Keplinger et al. (1973) found no (subjective) irritation after 5-min exposure to 23 or 36 mg NH_3/m^3, but some effects in 6 of 10 subjects given 52 mg/m^3. In a more thorough study, Verberk (1977) found slight irritation, but no effects on pulmonary function or hypersusceptibility, from 2-h exposures to 36 mg NH_3/m^3. Increasing the concentration to 57.6 mg/m^3 caused small (< 10%) decreases in pulmonary functions. Even higher concentrations (79.2, 100.8 mg/m^3) greatly increased irritation; the higher level was unbearable to all eight inexperienced subjects before the 2-h exposure was completed. Other studies, generally at higher concentrations for shorter periods, were consistent with these.

The most useful repeated dose study was that of Ferguson et al. (1977) involving 2 x 3-h exposures, 5 d/wk for 6 weeks, at concentrations of 18, 36, or 72 mg NH_3/m^3, in an industrial setting. They found some dose-dependent changes in respiratory function (increased 1-sec forced expiratory volume, but not changes in ventilatory capacity) and consistent irritation signs only at the highest concentration (72 mg/m^3). Some other studies (Mikhailuts, 1977; Sayfutdinov, 1968) report inhibition of odor thresholds to other compounds and lowered eye sensitivity to light at low concentrations (0.32-10.5 mg/m^3) of NH_3, with minor, transient changes in cardiovascular and respiratory functions at 6.1 and 10.5 mg/m^3. The importance of these findings is dubious.

Occupational Exposures

Several studies, summarized in Table S-3, have involved workers occupationally exposed to NH_3. Most of these studies have little value, their

TABLE S-2. SUMMARY OF HUMAN EXPERIMENTAL EXPOSURE TO NH_3

Level of Exposure (mg/m^3)	Exposure Time	Table No.	Effects
360-403.2 (several studies)	Acute	IV-1	Blood pressure decreased; NH_3 levels in the blood increased; rapidly reversible changes in lung functions; lacrimation but no coughing; widely varied subjective responses.
180-344	Acute	IV-1	Changes in lung functions at rest and during exercise; changes in exercise cardiac frequency.
144	Acute	IV-1	Lung function and slight cardiac changes.
96.5-106 (several studies)	Acute	IV-1	Significant lung function and cardiac changes, at rest and exercise; some strong irritation of eyes, nose, mouth or throat, though others were relatively unaffected.
50-79.2 (several studies)	Acute	IV-1	Slight lung function changes in some; reduced cardiac frequency in some; definite eye and throat irritation in some, though others relatively unaffected.
18-72	Repeated	IV-2	Occasional mild irritation; increased FEV_1 but not other respiratory or blood pressure parameters; apparent adaptation in the ability to withstand brief excursions to 144 mg/m^3.
51.8-57.6 (several studies)	Acute	IV-1	Slight decrease in lung functions; definite eye and slight throat irritation at the higher level; slight irritation of some at the lower level; odor detected.
36 (several studies)	Acute	IV-1	No lung function changes; slight to moderate irritation in some; odor detected.
36	Repeated	IV-2	No significant changes in lung function, blood pressure, rate of irritation or neurological response.
33.7	Acute	IV-1	Lowest concentration at which 4/4 detected the odor.
23	Acute	IV-1	9/10 detected the odor; no irritation.
21.6	Acute	IV-1	Faint irritation in some; odor detected.
13	Acute	IV-1	Increased NH_3 levels in blood and urine; decreased O_2 consumption; no EKG changes; rapid recovery.
10	Repeated	IV-2	Some changes in lung functions, heart rhythm, and odor sensitivity.
6.1	Repeated	IV-2	No change in lung functions or heart rhythm; changes in odor sensitivity.
3	Acute	IV-1	Tendency to decreased O_2 consumption; insignificant EKG changes; rapid recovery.
2.2	Repeated	IV-2	Decreases in some lung functions and camphor odor theshold.
0.45-1.0	Acute	IV-1	Range of thresholds of NH_3 perception for 22 people.
0.32-0.76	Repeated	IV-2	The upper range changed cerebral cortical activity; 0.32 mg/m^3 was the subthreshold level.
0.32-0.65	Repeated	IV-2	Upper levels decreased eye sensitivity to light; 0.32 mg/m^3 was the subthreshold value for eye sensitivity.

TABLE S-3. SUMMARY OF OCCUPATIONAL EXPOSURE TO NH_3

Level of Exposure (mg/m^3)	Length of Exposure	Table No.	Effects
3.6-144 (plus CO, CO_2, H_2S)	2-12 h/d	V-1	Mainly respiratory complaints; some eye irritation and nausea.
50-75	>10 y	V-1	Increased cancer rates compared to non-NH_3 production workers, and the general population of the GDR, especially of the lungs, stomach, lymphatic tissue, and urinary tract. Perhaps there was also exposure to asbestos.
10-40	5-10 y	V-1	Various signs of overexcitability of the nerve tracts by the end of the workday.
5-29	-	V-1	Higher incidence of chronic bronchitis and dyspnea; lower FEV_1.
18.3-26.3 (plus H_2SO_4)	-	V-1	~50% had slight or moderate impairment of lung function, the percentage decreasing over the years with decreasing NH_3 levels.
6-26 (plus NO_x)	-	V-1	Lower FEV_1 values.
≤20 (plus NO_x)	2 y	V-1	Increased incidence of upper respiratory tract disorders and xeroderma with increasing exposure time; biochemical changes indicating possible hepatic stress.

major faults being lack of precise exposure data and the presence of confounding variables such as smoking (a known source of NH_3 exposure) and exposure to other irritants.

The most useful study is that of Herrman and Viehrig (1979). Despite its faults, especially the few subjects involved, a decrease in ammonia exposure is well correlated with a decrease in impairments of lung function. The inverse effect (increased lung impairment with increased NH_3 exposure) was reported by Kujawska et al. (1977) and Giguz (1968).

Accidental Exposures

Table V-2 contains details of the reports of accidental overexposures, generally to massive concentrations for a few minutes. None gives actual concentrations; most involve only 1 or 2 persons. However, they do demonstrate that the effects of very high concentrations are qualitatively similar to those seen from the lower concentrations reported for experimental and occupational exposures. The most clear-cut dose-response curve is from Caplin (1941), the report with the greatest number of exposed persons (47). Nine victims had only "mild" exposure, giving acute pharyngitis and tracheitis with rapid recovery. The 25 victims of "moderate" exposure had more exaggerated symptoms, including acute bronchitis and bloody sputum. While 15/25 recovered completely, 6 died, 3 from bronchopneumonia (in those preantibiotic years) and 3 from pulmonary edema. The 11 victims of "severe" exposure were gravely ill, with pulmonary edema, intense dyspnea, etc.; 7 died.

The basic pattern is irritative damage followed by death or recovery, with no evidence of late sequelae other than rare pulmonary obstruction, possibly due to scarring.

OTHER POSSIBLE EXPOSURES TO AMMONIA

To put the levels of NH_3 encountered in automobile exhaust in some perspective, other common ammonia exposure sources are given here. The most obvious, and a frequent confounding factor in human studies, is cigarette smoke. Estimates of NH_3 levels in cigarette smoke vary with the type of tobacco and the investigator: 51-153 μg/nonfilter cigarette, 36 μg/filter cigarette (Sloan and Morie, 1974), and 25-29 μg/g of tobacco smoked (~ 50% being retained by the smoker; Bhown et al., 1971).

Human breath itself can contain measurable levels of NH_3, but it varies with the subject: 0.029-0.520 mg/m^3 (Larson et al., 1977), 0.1-1.50 mg/m^3 in healthy smokers, and 0.4-1.93 mg/m^3 in nonsmokers (Nefedov et al., 1969).

Ammonia can also be present in the ambient air. The average level of ammonia in urban air has been estimated to be about 20 ppb (~ 0.014 mg/m^3; NAS/NRC, 1972). Limits have been set on the levels which are to be allowed in the workplace air. The American Conference of Governmental Industrial Hygienists gives 18 mg NH_3/m^3 as the time-weighted-average threshold limit value, and 27 mg/m^3 as the short-term-exposure limit (ACGIH, 1981). For comparison, the Maximum Allowable Concentrations in air in the USSR for 1972 were 20 mg/m^3 in the workplace, and 0.2 mg/m^3 as both the one-time and average limit in populated places (USSR, 1972).

RECOMMENDED RANGE OF CONCERN

The available evidence is that the adverse effects of NH_3 are due to its irritation of mucous membranes, particularly in the eye and respiratory tract. Unless the exposure is lethal, recovery usually occurs. The odor threshold is regularly reported as being less than the irritation threshold. Therefore the odor threshold (the consensus opinion is about 5 ppm, 3.6 mg NH_3/m^3; NAS/NRC, 1972) is recommended as the upper bound of the range of concern.

Because of the lack of solid studies of effects at lower levels, and the routine recovery from nonlethal over-exposure, the lower bound would be an arbitrary margin of safety. We recommend 0.36 mg NH_3/m^3, below the lowest reported odor threshold.

Animal studies provide little assistance in setting ranges of concern because of the practical difficulties in determining an odor threshold in a nontalking creature.

SECTION I

INTRODUCTION

This report was compiled as the third of several tasks under Contract No. 68-03-2928, "Health Effects Support for the Emission Control Technology Division (U.S. Environmental Protection Agency, Ann Arbor, Michigan)." The goal of the project is to evaluate health effects literature on specific compounds emitted from automobiles equipped with emission-control devices (specifically catalytic converters), not for the purpose of creating a criteria document but to identify a range of concern or a no-observable-effect level for each compound to serve as guidance to automobile manufacturers in their development of future emission-control devices.

The present report was meant to be largely a series of charts or tables of pertinent data with the tests logically ordered according to exposure levels. The narrative summary was not meant to describe again each paper in detail. There are admittedly some disadvantages in not doing so; e.g., some of the gradations in effect the authors of a particular paper observed may be diluted or lost when the details are spread throughout an exceptionally large table, or between several tables. Papers described in a largely narrative fashion, however, often are difficult to compare. Results that appear within their source paper to be quite definitive may appear less so or even anomalous when juxtaposed in tabular format with other results from similar studies. Hence, the present format was designed to facilitate comparisons.

Literature related to health effects of inhaled NH_3 was collected mainly by computer search of TOXLINE and TOXBACK and manual search through the NRC Subcommittee report on ammonia. Approximately 200 papers and other documents were evaluated, but only about 50 contained original data suitable for tabulation.

Experimental animal and human exposure studies were evaluated and summarized by a senior Ph.D. pharmacologist. Occupational exposures were rated by an epidemiologist with an M.D. degree. Figure I-1 is the form used for rating documents by the project pharmacologist and epidemiologist. Each document was rated in a two-step procedure according to the applicability of its subject matter and to the quality of the experimental methodology. The letter assigned in rating the document A, B, C, or D was derived from the corresponding lower case letters under item 7 in Figure I-1. Thus, a study was rated A if it directly applies to or assists in establishing a range of concern for exposure to NH_3. The second part of the rating is the methodology score. The document reviewer checked off which score should be

Article No. 4997-3-_ _ _ _

CHECK WHERE APPROPRIATE:	PAPER DEFECTIVE 0	PAPER IS SUB-STANDARD 1	STANDARD QUALITY 2	SUPERIOR PAPER 3
1. Do they state/limit the problem?				
2. Adequacy of sample				
3. Replicability				
4. Controls/control procedures				
5. Completeness and comprehensibility of results				
6. Validity of conclusions, interpretation of data				

7. Applicability to health effects of NH_3 as guidance for establishing a range of concern for NH_3 in automobile exhaust.
(circle one)

a. Clearly, directly applies/assists in establishing a range of concern (Chronic human studies; acute exposure of humans if minimal effects.)

b. Research requires major inferences; potentially applicable. (Chronic animal studies; acute human, maximal effect; acute animal, minimal effects.)

c. Useful hints or suggestions; tentatively applicable. (Acute animal, lethal effects; studies in above categories but effects reported not appropriate.)

d. Not directly applicable (peripheral useful information).

Figure I-1 - Form for Report Rating.

given for each of the first six items in Figure I-1, and the total was written at the top of the page along with the letter that rated the paper's applicability. In some cases, such as reviews, theoretical papers, and low-rated foreign-language documents, a paper may have received an applicability rating (generally C or D) but none on methodology.

Data, including the MRI-assigned rating, from the A-, B-, and some C-rated papers were tabulated by a mid-level scientist. Information for each topic heading was looked for; so if blanks appear in the table, the reader can generally assume the data were not given. Information which was unclear in the original document but needed for tabulation is preceded in the tables by a qualifying word such as "apparently." Sometimes a group published several papers that described the same tests. To avoid redundancy, all pertinent papers were cited and the test was described as well as possible from all the papers' descriptions.

The final written summary of the tabulated data was also performed by a senior pharmacologist. This summary attempts to reflect objectively the scientific community's thought as a whole and does not reflect the tabular material by weight. The tables reflect the amount of data generated, and the summary puts the evaluated data in perspective with the overall scientific community's opinions.

SECTION II

BIOASSAY

The studies described in Table II-1 are considered bioassays because they do not deal with intact animals. They are all concerned with the effect of NH_3 on tracheal ciliary activity, and so mucociliary clearance and possibly the risk of microbial infection. The tracheas were either removed entirely or opened in situ and then exposed, generally for ≤ 45 min.

There are a few possibly helpful hints to be gained from these studies. The results of Dalhamn (1963) show a 95% reduction in the NH_3 concentration in the inhaled air by the time it reaches the trachea, indicating that the upper respiratory tract may be the site of much of the toxic symptoms. There appears to be a possible slight synergism between NH_3 and carbon particles (Dalhamn, 1963; Dalhamn and Reid, 1967). The effect of lower levels of NH_3 on ciliary movement is unclear, Dalhamn and Reid (1967) indicating no effect at 73.7-85.5 mg NH_3/m^3 and Dalhamn (1956) reporting a rapid effect at 2.2-64.8 mg NH_3/m^3. The former study is perhaps more useful because it deals with the repeated exposure of live animals. If so, the levels of NH_3 expected to be encountered in automotive exhaust should be of little concern in this respect, except perhaps in the presence of particulates.

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TABLE II-1. BIOASSAYS

Compound(s) and Concentration(s) in mg/m³ (ppm)	Temperature and Humidity	Mode of Exposure	Preparation Exposed	Description of Tests and Duration	Results	Reference and Rating
NH_3 1,440 (2,000) Carbon particles 2 (95% < 3 μm)	Not given	Not given	Live rabbits	Exposure was to NH_3 alone or with the particles for 45 min. Experimental details were not given, but the tracheas were apparently exposed while in place in the animals, and ciliary beat frequency determined cinematographically.	NH_3 alone caused a reduction in ciliary activity, though not its cessation. There was a possible slight synergism with carbon particles. This level in the inhaled air resulted in ~ 100 ppm in the tracheal air in live rabbits with cannulae inserted in the tracheas.	Dalhamn (1963) D-7
NH_3 180-720 (250-1,000)	37° 100%	Chamber	Excised rabbit trachea opened longitudinally	Ciliary activity was observed (method not given) for a 20-min exposure.	Ciliary activity stopped (recovery not considered) in ~ 5 min when exposed to 500-1,000 ppm. The time required was ≥ 20 min when exposed to ~ 250 ppm.	Dalhamn and Sjöholm (1963) D-6
NH_3 288-432 (400-600)	30-31°	Constant temperature tissue chamber	Excised rabbit tracheal tissue	Gas was delivered through a syringe at a rate near natural rabbit air flow for 10 min. Ciliary activity was observed through a microscope during exposure, and recovery in humid air or Ringer's solution.	Cessation of ciliary activity without recovery in Ringer's solution occurred in 10 min at 600 ppm. It occurred without recovery in air in 5 or 10 min at 500 or 400 ppm, respectively.	Cralley (1942) D-6
NH_3 54-121.7 (75-169)	34-37.5° 100%	Thermo-regulated chamber	Excised rabbit trachea opened longitudinally	Ciliary activity, including frequency, was observed (method not given) before and after a 45-min exposure to constant level of NH_3.	A concentration of ~ 100 ppm seemed to be the critical level influencing ciliary beating.	Dalhamn (1963) D-7
NH_3 73.7-85.5 (102.3-118.7) Carbon particles 3.46 (95% < 3 μm)	Not given	Not given	Live rats	Rats were exposed 5 h/d, 5 d/wk for 60 d, apparently in vivo. At the end, ciliary beating frequency was determined (probably cinematographically) while rats lay with tracheas exposed and opened lengthwise (unclear, but probably not while air flow was continuing). Exposure to NH_3 alone and with particles.	NH_3 alone had no effect on ciliary activity. Combined with carbon particles, beat frequency decreased significantly. 6/10 rats exposed to only NH_3 had moderate to severe histological damage to the tracheal mucosa.	Dalhamn and Reid (1967) C-7
NH_3 2.2-64.8 (3-90)	34° 90-95%	Chamber	Rat tracheas (unclear if they were excised or opened and exposed "in place")	Ciliary activity was continuously observed microscopically for < 10 min, with continuous gas flow over the tracheas.	Very rapid loss of ciliary movement: after 5-s exposure to 90 ppm and after 7-8 min exposure to 3 ppm. Recovery was also rapid, in 10 to 30 s after exposure stopped.	Dalhamn (1956) C-6

SECTION III

EXPERIMENTAL ANIMAL INHALATION EXPOSURES

The essential parameters of numerous animal inhalation exposure experiments are tabulated in this section (Tables III-1 to III-22). The primary organization of the data is by species, in order of increasing weight (bats to swine in this case). Within a species, studies are divided by dosing duration: acute exposure ($\leq$ 24 h), repeated exposure, and chronic exposure ($\geq$ 90 d). Within a single table, reported results are listed in order of decreasing exposure level.

The tables have been arranged in the aforesaid manner for the following reasons: (1) there were almost 200 separate tests being tabulated; (2) there are distinct differences in lung anatomy among the laboratory species used, and the differences seen in their relative responses may have been largely due to these anatomical differences; and (3) by putting the highest concentrations and worst effects first, one can more readily understand the significance of minor or less-severe changes occurring at lower levels.

However, a composite Table S-1 appears in the Summary. Because of the large amount of data, this table groups the results seen in various species only at levels $\leq$ 36 mg NH_3/m^3.

In the animal exposure tables in this section, the column headed Total Length of Expt. includes not only the total length of exposure to NH_3 but also any recovery time observed in the study. This recovery time was included to note the endurance or reversibility of the toxic effects.

TABLE III-1. BATS--ACUTE EXPERIMENTAL EXPOSURE TO NH$_3$

Compound(s) and Concentration(s) in mg/m³ (ppm)	Humidity	Mode of Exposure	Species/ Strain/ Age/Weight	No. of Test Animals	No. of Controls	Duration & Frequency of Exposure	Total Length of Expt.	Effects	Reference and Rating
NH$_3$ 3,960 (5,500)	Not given	Inhalation chamber	Bats, *Macrotus californicus*, 8.8-15.0 g	Unknown number out of group of 59 M+F used in study	Apparently served as own controls for heart and respiratory rates	< 1 h once	< 1 h	Decrease in heart rate and respiration, death in 40 min. Brain greatly congested, lungs edematous with large hemorrhages, distended heart, gall bladder, and urinary bladder, greatly distended stomach and intestines, and congested liver and kidneys.	Mitchell (1963) B-9
NH$_3$ 2,520 (3,500)	Not given	Inhalation chamber	Bats, *Macrotus californicus*, 8.8-15.0 g	Unknown number out of group of 59 M+F used in study	Apparently served as own controls for heart and respiratory rates	≤ 4 h once	≤ 4 h	Decrease in heart rate and respiration, death in 4 h. Brain greatly congested, lungs edematous with large hemorrhages, distended heart, gall bladder, urinary bladder, greatly distended stomach and intestines, and congested liver and kidneys.	Mitchell (1963) B-9
NH$_3$ 2,160-2,376 (3,000-3,300)	Not given	Inhalation chamber	Bats, *Macrotus californicus*, 8.8-15.0 g	Unknown number out of group of 59 M+F used in study	Apparently served as own controls for heart and respiratory rates	9 h once	9 h	The highest level "tolerated" for 9 h was 3,000 ppm. At 3,300 ppm the bats changed from nasal to mouth breathing. Oily condition developed on body hair.	Mitchell (1963) B-9
NH$_3$ 1,440 (2,000)	Not given	Inhalation chamber	Bats, *Macrotus californicus*, 8.8-15.0 g	Unknown number out of group of 59 M+F used in study	Apparently served as own controls for heart and respiratory rates	9 h once	9 h	In addition to eye irritation, reddening of skin and inflamed lips and mouth. Oily condition developed on body hair.	Mitchell (1963) B-9
NH$_3$ 972 (1,350)	Not given	Inhalation chamber	Bats, *Macrotus californicus*, 8.8-15.0 g	Unknown number out of group of 59 M+F used in study	Apparently served as own controls for heart and respiratory rates	9 h once	9 h	Apparent eye irritation with excessive lacrimation. Oily condition developed on body hair.	Mitchell (1963) B-9

TABLE III-2. MICE—ACUTE EXPERIMENTAL EXPOSURE TO NH_3

Compound(s) and Concentration(s) in mg/m^3 (ppm)	Humidity	Mode of Exposure	Species/ Strain/ Age/Weight	No. of Test Animals	No. of Controls	Duration & Frequency of Exposure	Total Length of Expt.	Effects	Reference and Rating
NH_3 360 (500) Followed by 10 min exposure to an aerosol of Pasteurella multocida, with no further NH_3.	Not given	Exposure chamber	Mice, avg. wt 25 ± 2 g (specific pathogen free)	49 M	49 M	8 h	13 d	21/49 died, not significantly different from control group.	Richard et al. (1978a) B-11

TABLE III-3. MICE--REPEATED DOSE EXPERIMENTAL EXPOSURE TO NH_3

Compound(s) and Concentration(s) in mg/m^3 (ppm)	Humidity	Mode of Exposure	Species/ Strain/ Age/Weight	No. of Test Animals	No. of Controls	Duration & Frequency of Exposure	Total Length of Expt.	Effects	Reference and Rating
NH_3 360 (500) Followed by 10 min exposure to an aerosol of Pasteurella multocida, with no further NH_3.	Not given	Exposure chamber	Mice, avg. wt 25 ± 2 g	49 M	50 M	168 h	19 d	42/49 died, a significant increase compared to the control group. Mortality also higher than the group exposed to NH_3 for only 8 h.	Richard et al. (1978a) B-11
NH_3 14.4 (20)	10-30%	Cabinet (336 ft^3)	Swiss Albino mice, 3-4 wk	4	3	7 d 14 d 21 d 28 d 42 d	42 d	No effect up to 6 wk. After 6 wk, lung tissue became dark red and more dense than control lung tissue, with pulmonary congestion, edema, and hemorrhage.	Anderson et al. (1964) B-12

TABLE III-4. RATS--ACUTE EXPERIMENTAL EXPOSURE TO NH_3

Compound(s) and Concentration(s) in mg/m³ (ppm)	Humidity	Mode of Exposure	Species/ Strain/ Age/Weight	No. of Test Animals	No. of Controls	Duration & Frequency of Exposure	Total Length of Expt.	Effects	Reference and Rating
NH_3 22,500 (31,300)	Not given	Well-ventilated chamber	Rats	50	0	32 min	-	Died in 32 min after severe dyspnea. Lung hemorrhages.	Lehmann (1886) B-9
NH_3 9,580-11,150 (13,300-13,600)	Not given	Well-ventilated chamber	Rats	41	0	3 h once	-	Slightly injured. No observable symptoms after exposure.	Lehmann (1886) B-9
NH_3 8,780 (12,200)	Not given	Well-ventilated chamber	Rats	40	0	4 h once	-	Slightly injured. No observable symptoms after exposure.	Lehmann (1886) B-9
NH_3 1,640-1,800 (2,280-2,500)	Not given	Well-ventilated chamber	Rats	15	0	2.5 h once	-	Same symptoms as after 1,555 mg/m³. Normal after exposure.	Lehmann (1886) B-9
NH_3 1,555 (2,160)	Not given	Well-ventilated chamber	Rats	Groups of 10 and 11	0	4.5 h once	-	Some secretion. Respiration fell to 10 then gradually rose to 45. Eyes mostly closed. Normal after exposure.	Lehmann (1886) B-9
NH_3 590-1,030 (820-1,430)	Not given	Well-ventilated chamber	Rats	8	0	5.5 h once	-	Quiet. Slight annoyance. Normal after exposure.	Lehmann (1886) B-9
NH_3 346-410 (480-570)	Not given	Well-ventilated chamber	Rats	3	0	4 h once	-	Very slight annoyance. Normal after exposure.	Lehmann (1886) B-9

TABLE III-5. RATS--REPEATED DOSE EXPERIMENTAL EXPOSURE TO NH_3

Compound(s) and Concentration(s) in mg/m³ (ppm)	Humidity	Mode of Exposure	Species/ Strain/ Age/Weight	No. of Test Animals	No. of Controls	Duration & Frequency of Exposure	Total Length of Expt.	Effects	Reference and Rating
NH_3 770 ± 55 (1,070)	50%	Modified Rochester-type inhalation chamber	Sprague-Dawley and Long-Evans rats	15	123 (4 died)	8 h/d, 5 d/wk, 6 wk	6 wk	No deaths. The lungs showed consistent nonspecific inflammatory changes. (Note the milder effects compared to the 455 mg/m³ exposure, and the different exposure schedules.)	Coon et al. (1970) B-12
NH_3 455 ± 23 (632 ± 32)	50%	Modified Rochester-type inhalation chamber	Sprague-Dawley and Long-Evans rats	50	123 (4 died)	Continuous 65 d	65 d	32/51 died by 25 d. 50 died by 65 d. All rats showed mild signs of dyspnea and nasal irritation. No histopathologic exams were made.	Coon et al. (1970) B-12
NH_3 360 (500)	Not given	Exposure chamber	Rats, avg. wt 196 ± 7 g (specific pathogen free)	27 M	27 M	1-8 wk	8 wk	At wk 3, nasal irritation and severe inflammation of the upper respiratory tract. No difference in the number of pulmonary alveolar macrophages. Food consumption and body weight significantly less than controls after 5 d.	Richard et al. (1978a) B-11
NH_3 180 (250). With intranasal inoculation of Mycoplasma pulmonis on day 7 of NH_3 exposure, both test and control groups.	51-69%	Exposure chamber	Fischer rats, 2-4 mo (specific pathogen free)	12	12 (matched on age, sex, and no./cage)	35 d	35 d	Increased incidence of gross and microscopic lung lesions, and severity of rhinitis, otitis, tracheitis, and pneumonia. All symptoms are characteristic of mycoplasmosis, and seemed to increase with increasing NH_3 concentration (25, 50, 100, 250 ppm).	Broderson et al. (1976) B-12

(continued)

TABLE III-5. (continued)

Compound(s) and Concentration(s) in mg/m³ (ppm)	Humidity	Mode of Exposure	Species/ Strain/ Age/Weight	No. of Test Animals	No. of Controls	Duration & Frequency of Exposure	Total Length of Expt.	Effects	Reference and Rating
NH_3 180 (250)	66 ± 5%	Exposure chamber	Fischer rats, 2-4 mo (specific pathogen free)	12	12 (matched on age, sex, and no./cage)	35 d	35 d	Nasal lesions and histologic alterations in both respiratory and olfactory epithelia in the test group only.	Broderson et al. (1976) B-12
NH_3 155 ± 32 (215)	50%	Modified Rochester-type inhalation chamber	Sprague-Dawley and Long-Evans rats	15	123 (4 died)	8 h/d, 5 d/wk, 6 wk	6 wk	No deaths, visible signs of toxicity, or gross tissue abnormalities. Hematological values normal.	Coon et al. (1970) B-12
NH_3 152.6 (212) With intranasal inoculation of Mycoplasma pulmonis on day 7 of NH_3 exposure, both test and control groups.	69 ± 5%	Shoe box cage with no change of bedding	Fischer rats, 2-4 mo (specific pathogen free)	22	24 (NH_3 level: 1.44 ± 4.32 mg/m³)	37 d	37 d	Snuffling, sporadic head shaking, moderate dyspnea and apnea by day 14, rough hair coats, and hunched posture. Increased incidence of lung lesions and severity of entire respiratory tract lesions in test animals compared to controls.	Broderson et al. (1976) B-12
NH_3 108 (150)	Not given	Shoe box cages with filter caps, and bedding not change	Sherman rats, 2-4 mo (specific pathogen free)	10	10 (NH_3 level: 7.2 ± 12.9 mg/m³)	75 d	75 d	Excessive blinking of the eyes after 1 wk. Nasal lesions in the test group only. Histologic changes in respiratory and olfactory epithelia.	Broderson et al. (1976) B-12
NH_3 77.8 (108) With intranasal inoculation of Mycoplasma pulmonis on day 7 of NH_3 exposure, both test and control groups.	69 ± 5%	Shoe box cages without bedding changes	Sherman rats	24	23 (NH_3 level: 7.9 ± 13.7 mg/m³)	42 d	42 d	Snuffling, sporadic head shaking, moderate dyspnea and apnea beginning day 14, rough hair coats and hunched posture. Increased incidence of lung lesions and severity of respiratory tract lesions (except otitis).	Broderson et al. (1976) B-12

(continued)

TABLE III-5. (continued)

Compound(s) and Concentration(s) in mg/m³ (ppm)	Humidity	Mode of Exposure	Species/ Strain/ Age/Weight	No. of Test Animals	No. of Controls	Duration & Frequency of Exposure	Total Length of Expt.	Effects	Reference and Rating
NH_3 72 (100) With intranasal inoculation of *Mycoplasma pulmonis* on day 7 of NH_3 exposure, both test and control groups.	51-69%	Exposure chamber (bedding changed daily)	Fischer rats, 2-4 mo (specific pathogen free)	12	12 (matched on age, sex, and no./cage)	35 d	35 d	Increased incidence of gross and macroscopic lung lesions, and increased severity of rhinitis, otitis, tracheitis, and pneumonia. All are typical of mycoplasmosis.	Broderson et al. (1976) B-12
NH_3 64.8 (90)	40-80%	Climate-proof case	Wistar rats	32 M (3 separate expts. were done)	32 M	50-56 d	56 d	Test done at 10°C: decreased percent body weight increase and food consumption at wk 4, with some recovery by wk 7. Test done at 22°C: no effect on body weight increase or food consumption. All tests showed increased hemoglobin content.	Stolpe and Sedlag (1976) B-11
NH_3 36 (50) With intranasal inoculation of *Mycoplasma pulmonis* on day 7 of NH_3 exposure, both control and test groups.	51-69%	Exposure chamber (bedding changed daily)	Fischer rats, 2-4 mo (specific pathogen free)	12	12 (matched on age, sex, and no./cage)	35 d	35 d	Large increase in gross lesions and slight increase in microscopic lesions. Increased severity of rhinitis, otitis, and pneumonia. All symptoms are typical of mycoplasmosis.	Broderson et al. (1976) B-12
NH_3 36 (50)	50-80%	Climate-proof case	Wistar rats, 40-45 d, 90-140 g	21 M (2 trials with 2 groups of animals)	28 M	50 or 52 d	52 d	Test done at 10°C: reduced percent body weight increase at 4 wk, near recovery by wk 7, and food consumption was above that of the controls. Test done at 22°C: no effect by wk 7 on body weight increase, food consumption, or hematocrit values.	Stolpe and Sedlag (1976) B-11

(continued)

TABLE III-5. (continued)

Compound(s) and Concentration(s) in mg/m³ (ppm)	Humidity	Mode of Exposure	Species/ Strain/ Age/Weight	No. of Test Animals	No. of Controls	Duration & Frequency of Exposure	Total Length of Expt.	Effects	Reference and Rating
NH_3 21.6 (30)	50-80%	Climate-proof case	Wistar rats, 40-45 d, 90-140 g	13 M	13 M	52 d	52 d	No effect on body weight increase, food consumption, or hematocrit values at 4 or 7 wks.	Stolpe and Sedlag (1976) B-11
NH_3 20 ± 0.1	Not given	Exposure chamber	Albino rats	15 M	15 M	84 d	84 d	About 15% decrease in the latent period of reflex response to faint electric stimulus only in the 1st mo. Inhibition of cholinesterase activity in, and redox function of, the blood (recovery after exposure stopped). Increased coproporphyrin levels in the urine. No macroscopic changes in the organs.	Saifutdinov (1966 and 1968) B-9 B-7
NH_3 18 (25) With intranasal inoculation of Mycoplasma pulmonis on day 7 of NH_3 exposure, both test and control groups.	51-69%	Exposure chamber (bedding changed daily)	Fischer rats, 2-4 mo (specific pathogen free)	24	24 (matched on age, sex, and no./cage)	37 or 49 d	49 d	Greater incidence of gross and microscopic lung lesions, otitis, and pneumonia in both trials. Increased rhinitis and tracheitis in 1/2 trials. All symptoms are typical of mycoplasmosis.	Broderson et al. (1976) B-12
NH_3 2 ± 0.021	Not given	Exposure chamber	Albino rats	15 M	15 M	84 d	84 d	No effect on latent period of reflex response, blood cholinesterase activity, or urine coproporphyrin levels. Some inhibition of blood redox function during first month of exposure.	Saifutdinov (1966 and 1968) B-9 B-7
NH_3 0.2 ± 0.002	Not given	Exposure chamber	Albino rats	15 M	15 M	84 d	84 d	No effect on latent period of reflex response, blood cholinesterase activity and redox function, or urine coproporphyrin levels. Author recommends this as the mean daily maximum permissible concentration in the USSR.	Saifutdinov (1966 and 1968) B-9 B-7

TABLE III-6. RATS--CHRONIC EXPERIMENTAL EXPOSURE TO NH_3

Compound(s) and Concentration(s) in mg/m³ (ppm)	Humidity	Mode of Exposure	Species/ Strain/ Age/Weight	No. of Test Animals	No. of Controls	Duration & Frequency of Exposure	Total Length of Expt.	Effects	Reference and Rating
NH_3 470 ± 16 (6$\bar{5}$3)	50%	Modified Rochester-type inhalation chamber	Sprague-Dawley and Long-Evans rats	15	123 (4 died)	Continuous 90 d	90 d	13/15 died. Hematological values did not vary from controls. Histopathologic examination revealed focal or diffuse interstitial pneumonitis in all animals. Other histopathology of the liver, kidneys, heart, and bronchi seen, with similar but lesser changes seen in the controls.	Coon et al. (1970) B-12
NH_3 262 ± 10 (3$\bar{6}$4)	50%	Modified Rochester-type inhalation chamber	Sprague-Dawley and Long-Evans rats	49	123 (4 died)	Continuous 90 d	90 d	No deaths or pronounced symptoms of toxicity. ~ 25% animals had mild nasal discharge. Hematological results were normal except that 4 rats had slightly high leukocyte counts. Microscopic examination showed nonspecific circulatory and degenerative changes in lungs and kidneys but they may not be related to ammonia inhalation.	Coon et al. (1970) B-12
NH_3 127 ± 8 (1$\bar{7}$6)	50%	Modified Rochester-type inhalation chamber	Sprague-Dawley and Long-Evans rats	48	123 (4 died)	Continuous 90 d	90 d	No deaths or signs of toxicity in any of the animals: hematological values, liver histochemical results, or microscopic exam for nonspecific inflammation of the lungs.	Coon et al. (1970) B-12
NH_3 40 ± 2 (5$\bar{6}$)	50%	Modified Rochester-type inhalation chamber	Sprague-Dawley and Long-Evans rats	15	123 (4 died)	Continuous 114 d	114 d	No deaths or signs of toxicity. Necropsy observations were normal. 1 rat had lipid filled macrophages in its lung, but it was not deemed significant.	Coon et al. (1970) B-12

(continued)

TABLE III-6. (continued)

Compound(s) and Concentration(s) in mg/m³ (ppm)	Humidity	Mode of Exposure	Species/ Strain/ Age/Weight	No. of Test Animals	No. of Controls	Duration & Frequency of Exposure	Total Length of Expt.	Effects	Reference and Rating
NH_3 20 ± 0.6	Not given	Exposure chamber	Albino rats	11 M	9 M	5-6 h/d, 3-3.5 mo	3.5 mo	No significant changes in vitamins A, B_1, ascorbic acid, pyruvic acid levels in the blood, body weight, or weight coefficients of the organs. Decrease in total B_2 content of the blood, liver, and kidneys. Decrease in nicotinamide coenzymes in the adrenals, cerebral hemispheres, and skeletal muscles.	Nizhegorodov and Kalinin (1967) D-6
NH_3 19 ± 0.16	Not given	Exposure chamber	Albino rats	8 M	6 M	5-6 h/d, 6.5-7 mo	7 mo	No change in liver vitamin A content. Decreased vitamin B_1 in the blood and liver. Increased total ascorbic acid content of the adrenals, liver, and skeletal muscles. Unchanged levels of nicotinamide coenzymes. Body weight loss of 10 g. Increased weight of spleen, lungs, and brain.	Nizhegorodov and Kalinin (1967) D-6
NH_3 6 ± 0.1 With 3 short intranasal exposures to Staphylococcus strain No. 209, each followed by 8-10 d without NH_3 exposure.	Not given	Not given	Rats	64	64 (32 with microbial exposure, 32 without)	7 h/d, 5 times/wk, for 4 mo	4 mo	By the end of the study, the test group had more histochemical and pathomorphological changes of both the upper and lower respiratory tracts than the infection-control group. Particularly decreased protective phagocytic action, increased histamine in the lung, and increased macrophage but decreased glycogen index.	Mikhailuts et al. (1979) B-10

(continued)

TABLE III-6. (continued)

Compound(s) and Concentration(s) in mg/m^3 (ppm)	Humidity	Mode of Exposure	Species/ Strain/ Age/Weight	No. of Test Animals	No. of Controls	Duration & Frequency of Exposure	Total Length of Expt.	Effects	Reference and Rating
NH_3 3 ± 0.08 With 3 short intranasal exposures to *Staphylococcus* strain No. 209, each followed by 8-10 d without NH_3 exposure.	Not given	Not given	Rats	32	64 (32 with microbial exposure, 32 without)	7 h/d, 5 times/wk, for 4 mo	4 mo	Caused no reliable disturbances in the period after respiratory infection.	Mikhailuts et al. (1979) B-10

TABLE III-7. GUINEA PIGS--ACUTE EXPERIMENTAL EXPOSURE TO NH_3

Compound(s) and Concentration(s) in mg/m³ (ppm)	Humidity	Mode of Exposure	Species/ Strain/ Age/Weight	No. of Test Animals	No. of Controls	Duration & Frequency of Exposure	Total Length of Expt.	Effects	Reference and Rating
NH_3 1,858-3,312 (2,580-4,600)	Not given	Well-ventilated chamber	Guinea pigs	20	0	10 h, once	-	Moderate symptoms of irritation. Respiration 21, 13, 18, 25. Some salivary secretion. Cornea clear although eyes remained open. Killed after 24 h with $CHCl_3$. Entire lung hyperemic and somewhat edematous. Upper lobe had numerous small hemorrhages; left lower lobe completely empty of air. Trachea without ecchymoses.*	Lehmann (1886) B-9
NH_3 1,634-1,872 (2,270-2,600)	Not given	Well-ventilated chamber	Guinea pigs	18	0	8.33 h, once (exposed 4 day previously to 4,600 ppm for 10 h)	-	Very quiet. Slight symptoms of irritation. Corneas slightly cloudy. Killed by $CHCl_3$ immediately after the exposure. Purulent-mucous bronchitis. Numerous hemorrhages in the lower and middle lobes of the lungs apparently from the earlier exposure.	Lehmann (1886) B-9
NH_3 590-1,030 (820-1,430)	Not given	Well-ventilated chamber	Guinea pigs	7	0	5.5 h	-	Symptoms of irritation. Respiration slowed to 10.	Lehmann (1886) B-9
NH_3 346-410 (480-570)	Not given	Well-ventilated chamber	Guinea pigs	2	0	4 h, once	-	Slight symptoms of irritation. Uninjured after exposure.	Lehmann (1886) B-9

* Ecchymoses are small hemorrhagic spots in the skin or mucous membrane forming nonelevated, rounded or irregular, blue or purplish patches.

TABLE III-8. GUINEA PIGS--REPEATED DOSE EXPERIMENTAL EXPOSURE TO NH_3

Compound(s) and Concentration(s) in mg/m³ (ppm)		Humidity	Mode of Exposure	Species/ Strain/ Age/Weight	No. of Test Animals	No. of Controls	Duration & Frequency of Exposure	Total Length of Expt.	Effects	Reference and Rating
NH_3	770 ± 55 (1,070)	50%	Modified Rochester-type inhalation chamber	Princeton-derived guinea pigs	15	73	8 h/d, 5 d/wk, 6 wk	6 wk	No deaths. Lungs showed consistent nonspecific inflammatory changes.	Coon et al. (1970) B-12
NH_3	155 ± 32 (215)	50%	Modified Rochester-type inhalation chamber	Princeton-derived guinea pigs	15	73	8 h/d, 5 d/wk, 6 wk	6 wk	No deaths, visible signs of toxicity, or gross tissue abnormalities. Hematological values normal.	Coon et al. (1970) B-12
NH_3	36 (50)	10-30%	Cabinet (336 ft³)	Guinea pigs, 6-8 wk	6	3	6 wk continuous	6 wk	Dark red and dense lungs; pulmonary edema, congestion, and hemorrhage; congestion of the liver; enlarged and congested spleen.	Anderson et al. (1964) B-12
NH_3	14.4 (20)	10-30%	Cabinet (336 ft³)	Guinea pigs, 6-8 wk	2 2 2 2 2	3 3 3 3 3	7 d 14 d 21 d 28 d 42 d continuous	6 wk	No effect up to 6 wk. After 6 wk: dark red and dense lung tissue, and pulmonary congestion, edema and hemorrhage.	Anderson et al. (1964) B-12

TABLE III-9. GUINEA PIGS--CHRONIC EXPERIMENTAL EXPOSURE TO NH_3

Compound(s) and Concentration(s) in mg/m^3 (ppm)	Humidity	Mode of Exposure	Species/ Strain/ Age/Weight	No. of Test Animals	No. of Controls	Duration & Frequency of Exposure	Total Length of Expt.	Effects	Reference and Rating
NH_3 470 ± 16 (653)	50%	Modified Rochester-type inhalation chamber	Princeton-derived guinea pigs	15	73	90 d continuous	90 d	4 died. Hematological values did not vary from controls. Histopathological examination revealed focal or diffuse interstitial pneumonitis in all animals. Other histopathology of the liver, kidneys, heart, and bronchi seen in some animals, with similar but lesser changes in the control group.	Coon et al. (1970) B-12
NH_3 40 ± 2 (56)	50%	Modified Rochester-type inhalation chamber	Princeton-derived guinea pigs	15	73	114 d continuous	114 d	No deaths or signs of toxicity. Necropsy observations were normal.	Coon et al. (1970) B-12

TABLE III-10. CHICKENS--ACUTE EXPERIMENTAL EXPOSURE TO NH_3

Compound(s) and Concentration(s) in mg/m³ (ppm)	Humidity	Mode of Exposure	Species/ Strain/ Age/Weight	No. of Test Animals	No. of Controls	Duration & Frequency of Exposure	Total Length of Expt.	Effects	Reference and Rating
NH_3 72 (100)	Not given	"Cabinet"	Adult hens, 8-10 mo	Not given, but probably small	Served as own controls	Not given	Not given	Significant decrease in respiration rates of 10.5-23.9% as measured by pneumograph or crissall feather movement. Significant 12.5-14.7% decrease in respiration depth in 2/3 observations.	Charles and Payne (1966a) B-12
NH_3 72 (100)	Not given	Small respiration chamber (0.22 m³)	Adult hens, 11 mo	Unclear, but maybe 4	Served as own controls	Not given	Not given	Significant 23.1% decrease in respiration rate, as measured by indirect calorimetry of carbon dioxide production, in 1/2 tests.	Charles and Payne (1966a) B-12
NH_3 54 (75)	Not given	"Cabinet"	Adult hens	15	Served as own controls	15 min	30 min	Statistically significant increase in blood pH (from brachial vein) from 6.447 to 6.563.	Charles and Payne (1966a) B-12

TABLE III-11. CHICKENS--REPEATED DOSE EXPERIMENTAL EXPOSURE TO NH_3

Compound(s) and Concentration(s) in mg/m³ (ppm)		Humidity	Mode of Exposure	Species/ Strain/ Age/Weight	No. of Test Animals	No. of Controls	Duration & Frequency of Exposure	Total Length of Expt.	Effects	Reference and Rating
NH_3	720 (1,000)	10-30%	Cabinet (336 ft³)	Leghorn chickens, 6-8 wk	2	3	Continuous 3 d	14 d	After 3 days: photophobia, rubbing of eyes, and lacrimation.	Anderson et al. (1964) B-12
					2	3	8 d		After 8 days: corneal opacities, followed by erosions by the surface layer of the cornea.	
					8	3	14 d		After 14 days: nearly all the birds had bilateral corneal opacities of varying severity, pulmonary congestion, edema, and hemorrhage as well as congestion of the liver and spleen and erosion of the cornea.	
NH_3	144 (200)	10-30%	Cabinet (336 ft³)	Leghorn chickens, 6-8 wk	2	3	Continuous 7 d	21 d	Obvious signs of discomfort during the first few days of exposure were considerable rubbing of the eyes, slight lacrimation, anoxeria, and weight loss. At necropsy, gross changes were only in the respiratory system. All eye irritation had disappeared. Histopathological changes were pulmonary edema, congestion, and hemorrhage. The tissue had an ammonia odor.	Anderson et al. (1964) B-12
					2	3	10 d			
					2	3	13 d			
					2	3	15 d			
					2	3	17 d			
					2	3	19 d		Above plus liver congestion and a slight clouding of the cornea.	
					2	3	21 d			

(continued)

TABLE III-11. (continued)

Compound(s) and Concentration(s) in mg/m³ (ppm)	Humidity	Mode of Exposure	Species/ Strain/ Age/Weight	No. of Test Animals	No. of Controls	Duration & Frequency of Exposure	Total Length of Expt.	Effects	Reference and Rating
NH_3 ~ 14.4-115.2 (~ 20-160) (General increase with time, with many fluctuations)	~ 6-9.5 grains of water/ft³ of atmosphere	Environmental pens	Chicks of a light/heavy commercial broiler cross, 1 d	120 F exposed, only 24 actually measured for effects	Apparently none	Wks 7-10 (exposed in the first 6 wk to unknown, but mainly lower, NH_3 levels)	10 wk	During wks 4-7, had higher weights than chickens exposed to 5-50, 10-80, or 10-45 ppm. By wk 10, had significantly lower weights than the other groups. By the end of the expt., 20/24 had ulcerations of the eye, many more than the other groups.	Valentine (1964) B-10
NH_3 72 (100)	Not given	"Cabinet"	Adult hens, 8-10 mo	Not given, but probably small	Served as own controls	3 or 4 wk	Not given	Significant 18.4% decrease in respiration rate only for those with 4 wk acclimatization, as measured by crissal feather movement.	Charles and Payne (1966a) B-12
NH_3 72 (100)	50.1%	Exposure chambers with wire floor for removal of droppings	White Rock x Light Sussex broiler-type chickens, 4 wk	10 M	10 M	19 d	37 d	Significant growth rate decrease in the last wk of exposure, due to a 14.5% reduction of voluntary food intake. Consumption did not return to normal until 12 d after cessation of NH_3 exposure.	Charles and Payne (1966a) B-12
NH_3 ~ 7.2-57.6 (~ 10-80) (Fluctuated with time, generally < 36 mg/m³ except for last week)	~ 6-9.5 grains of water/ft³ atmosphere	Environmental pens	Chicks of a light/heavy commercial broiler cross, 1 d	120 F exposed, only 24 actually measured for effects	Apparently none	Wks 7-10 (exposed in the first 6 wk to unknown, but mainly lower, levels)	10 wk	Significantly lower weight than group exposed to 20-160 ppm, during wks 3, 4, and 6. By wk 10, lower weight than the group exposed to 10-45 ppm, but higher weight than the group exposed to 20-160 ppm. 5/24 had eye ulcerations.	Valentine (1964) B-10

(continued)

TABLE III-11. (continued)

Compound(s) and Concentration(s) in mg/m³ (ppm)		Humidity	Mode of Exposure	Species/ Strain/ Age/Weight	No. of Test Animals	No. of Controls	Duration & Frequency of Exposure	Total Length of Expt.	Effects	Reference and Rating
NH_3	56.2 (78)	64.0%	Exposure chambers without litter, and the droppings removed daily	White Leghorn chickens, 11 wk, 1,250 g	27 F	27 F	7 wk	30 wk	Significantly decreased food consumption during wks 15-30 and live-weight gain during last 4 wk of exposure. Came into lay later, slightly larger eggs, and sexual maturity delayed 2 wk.	Charles and Payne (1966a) B-12
NH_3	38.2 (53)	64.7%	Exposure chambers, without litter, and the droppings removed daily	White Leghorn chickens, 11 wk, 1,250 g	27 F	27 F	7 wk	30 wk	Significantly decreased egg production (20%) during wks 23-26 (after exposure), and slightly heavier eggs during the whole period. Sexual maturity delayed 1 wk. Slight decrease in food consumption from wk 15 to wk 38. No change in live-weight gain.	Charles and Payne (1966a) B-12
NH_3	36.7 (51)	50.1%	Exposure chambers with wire floor for removal of droppings	White Rock x Light Sussex broiler-type chickens, 4 wk	10 M	10 M	33 d	33 d	Food consumption decreased slightly after day 12 of exposure. No differences in growth rate occurred.	Charles and Payne (1966a) B-12
NH_3 Newcastle infectious bronchitis (Mass.) (NC-IB) vaccination was administered at 21 d of age by aerosol means.	36 (50)		Chambers in an environmentally controlled building	Indian River broiler cockerels, 1-d-old	312 M; 156 for each exposure time	156 M	28 d or 49 d	49 d	No difference in avg. body wt. for either exposure time compared to controls or other exposure groups at any time. No difference in feed efficiency at day 28. By day 49, the avg. feed efficiency of the 49-d exposure group (2.44) was significantly less than that of the 28-d group (2.16), all other groups exposed to lower levels (2.08-2.35), and the controls (2.02). Scores for lesions of the right posterior thoracic air sac membrane were never significantly different from scores for control or other exposure groups. No significant differences in avg. paired lung wts. or avg. bursa of Fabricius wts.	Paveny et al. (1981) C-13

(continued)

TABLE III-11. (continued)

Compound(s) and Concentration(s) in mg/m³ (ppm)	Humidity	Mode of Exposure	Species/ Strain/ Age/Weight	No. of Test Animals	No. of Controls	Duration & Frequency of Exposure	Total Length of Expt.	Effects	Reference and Rating
NH_3 18 and 36 (25 and 50) Newcastle infectious bronchitis (Mass.) (NC-IB) vaccination was administered at 21 d of age by aerosol means.		Chambers in an environmentally controlled building	Indian River broiler chickens, 1-d-old	156 M	156 M	28 d at 36 mg/m³; 21 d at 18 mg/m³	49 d	No difference in avg. body wt. compared to controls or other exposure groups at any time. No differences in avg. feed efficiencies at d 28. By d 49, avg. feed efficiency (2.35) was significantly greater than that for 49-d exposure to 36 mg/m³, and less than controls (2.02) or 28-d exposure to 18 mg/m³ (2.08). Scores for lesions of the right posterior thoracic air sac membranes were never significantly different from those for control or other exposure groups. No significant differences in the avg. wts. of paired lungs or bursa of Fabricius.	Caveny et al. (1981) C-13
NH_3 36 (50) Followed by a 3-min exposure to an aerosol of Newcastle disease virus (~ 6 ELD_{50}'s/L), both test and control groups.	Not given	Controlled environment cabinet (336 ft³)	Leghorn chickens, 6-8 wk	12	12	48 h	17 d	Significant increase in the percent of birds infected in the test group (100%) compared to controls (~ 40%). Gross and microscopic pathology the same in both groups.	Anderson et al. (1964) B-12
NH ~ 3.6-36 (~ 5-50) (generally < 29 until the last week)	~ 4.5-7 grains of water/ft³ of atmosphere	Environmental pens	Chicks of a light/heavy commercial broiler cross, 1 d	120 F exposed, but only 24 actually measured for effects	Apparently none done	Wks 7-10 (exposed in the first 6 wk to unknown, but mainly lower, levels)	10 wk	During wks 4-7, significantly lower weights than the group exposed to 20-160 ppm. By wk 10, higher weights than that group. Consistently lower weights than group exposed to 10-45 ppm. No eye ulcerations.	Valentine (1964) B-10
NH_3 ~ 7.2-32.4 (~ 10-45) (some fluctuations, and general increase with time)	~ 5-6.5 grains of water/ft³ of atmosphere	Environmental pens	Chicks of a light/heavy commercial broiler cross, 1 d	120 F exposed, but only 24 actually measured for effects	Apparently none done	Wks 7-10 (exposed in the first 6 wk to unknown, but mainly lower, levels)	10 wk	By wk 10, significantly higher weight than groups exposed to 20-160 or 10-80 ppm. No eye ulcerations.	Valentine (1964) B-10

(continued)

TABLE III-11. (continued)

Compound(s) and Concentration(s) in mg/m^3 (ppm)	Humidity	Mode of Exposure	Species/ Strain/ Age/Weight	No. of Test Animals	No. of Controls	Duration & Frequency of Exposure	Total Length of Expt.	Effects	Reference and Rating
NH_3 ~ 30.2 (~ 45) Measurement was made at the end of the expt.; values probably varied during exposure.		Partially enclosed wire cage, with accumulation of fecal matter	White Rock chickens, 4 wk	5 M 7 F	3 M 2 F, exposed to ~ 5.3 mg NH_3/m^3	12 wk	12 wk	A statistically significant increase in the avg. rate of hemoglobin formation by the 4th wk of exposure. Then a steady decrease in hemoglobin formation, significantly below other treatments and "controls" by the 12th wk of exposure. Differences between sexes were reported. Birds developed keratoconjunctivitis. 3/12 developed unilateral or bilateral blindness. 2 of 5 M died between 2nd and 3rd month. No change in feed consumption.	Gaspar et al. (1961) C-9
NH_3 18 (25) Newcastle infectious bronchitis (Mass.) (NC-IB) vaccination was administered at 21 d of age by aerosol means.		Chambers in an environmentally controlled building	Indian River broiler chickens, 1-d-old	312 M; 156 for each exposure time	156 M	28 d or 49 d	49 d	No difference in avg. body wt., for either exposure length, compared to controls or other exposure groups at any time. No differences in avg. feed efficiencies at day 28. By day 49, the avg. feed efficiency (2.35) of the 49-d exposure group was less than that of the 28-d group (2.08) and the controls (2.02), and greater than that for the group exposed to 36 mg/m^3 for 49 d. Scores for air sac lesions were never significantly different from those for controls or other exposure groups. No significant differences in the avg. wts. of paired lungs or bursa of Fabricius.	Caveny et al. (1981) C-13
NH_3 ~ 16.6 (~ 23) Measurement was made at the end of the expt.; values probably varied during exposure.		Partially enclosed wire cage, and weekly removal of fecal matter	White Rock chickens, 4 wk	7 M 5 F	3 M 2 F, exposed to ~ 5.3 mg NH_3/m^3	12 wk	12 wk	No difference in the avg. rate of hemoglobin formation compared to the "control" values. Rate of increase of hemoglobin levels was higher in males than females. No change in feed consumption.	Gaspar et al. (1961) C-9

(continued)

TABLE III-11. (continued)

Compound(s) and Concentration(s) in mg/m³ (ppm)		Humidity	Mode of Exposure	Species/ Strain/ Age/Weight	No. of Test Animals	No. of Controls	Duration & Frequency of Exposure	Total Length of Expt.	Effects	Reference and Rating
NH_3 Followed by a 3-min exposure to aerosol of Newcastle disease virus (6 ELD_{50}'s/L), both test and control groups.	14.4 (20)	Not given	Con-trolled-environ-ment cabinet (336 ft³)	Leghorn chickens, 6-8 wks	12	12	72 h	18 d	Significant increase in the percent of birds infected in the test group (100%) compared to the control group (~ 50%). Gross and microscopic pathology was the same in both groups.	Anderson et al. (1964) B-12
NH_3 Followed by a 3-min exposure to an aerosol of Newcastle disease virus (3 ELD_{50}'s/L), both test and control groups.	14.4 (20)	Not given	Con-trolled-environ-ment cabinet	Leghorn chickens, 6-8 wks	12	12	72 h	18 d	Statistically insignificant increase in percent of birds infected. Gross and microscopic pathology of test and control groups the same.	Anderson et al. (1964) B-12
NH_3	14.4 (20)	10-30%	Cabinet (336 ft³)	Leghorn chickens, 6-8 wk	6	3	Continuous 12 wk	12 wk	Lungs were dark red and more dense when compared to the controls. Microscopic examination revealed pulmonary congestion, edema, and hemorrhage.	Anderson et al. (1964) B-12
NH_3	14.4 (20)	10-30%	Cabinet (336 ft³)	Leghorn chickens, 6-8 wk	3	3	Continuous 6 wk	6 wk	Darker colored and denser lung tissue than controls. Microscopic examination revealed pulmonary congestion, edema, and hemorrhage.	Anderson et al. (1964) B-12
NH_3	14.4 (20)	10-30%	Cabinet (336 ft³)	Leghorn chickens, 6-8 wk			Continuous	28 d	Exposure for 24 h was followed by a slight increase in mucous secretion. Condition disappeared after 3 or 4 days. No significant pathology. No obvious signs of discomfort.	Anderson et al. (1964) B-12
					3	3	7 d			
					3	3	14 d			
					3	3	21 d			
					3	3	28 d			

TABLE III-12. RABBITS--ACUTE EXPERIMENTAL EXPOSURE TO NH_3

Compound(s) and Concentration(s) in mg/m³ (ppm)	Humidity	Mode of Exposure	Species/ Strain/ Age/Weight	No. of Test Animals	No. of Controls	Duration & Frequency of Exposure	Total Length of Expt.	Effects	Reference and Rating
NH_3 14,400 (20,000)	Not given	Artificial respiration of curarized animals	"Fauve de Bourgogne" rabbits, avg. wt 2.5 kg	Unknown no. of M (perhaps just 1)	Served as own controls	60 min	180 min	Rapid increase in "total index of intoxication": strong bradycardia within 1 min, profound changes in ECG, pulmonary infarctions and edema, blood acidosis and elevated pO_2, and deterioration of EEG near time of death (after ~ 30 min of NH_3 exposure).	Richard et al. (1978b) B-10
NH_3 7,200 (10,000)	Not given	Artificial respiration of curarized animals	"Fauve de Bourgogne" rabbits, avg. wt 2.5 kg	Unknown no. of M (perhaps just 1)	Served as own controls	60 min	180 min	Rapid increase in "total index of intoxication": strong bradycardia within 1 min, ECG profoundly changed within 20 min, pulmonary infarctions and edema, blood acidosis and elevated pO_2, deterioration of EEG near time of death.	Richard et al. (1978b) B-10
NH_3 5,400 (7,500)	Not given	Artificial respiration of curarized animals	"Fauve de Bourgogne" rabbits, avg. wt 2.5 kg	Unknown no. of M (perhaps just 1)	Served as own controls	60 min	180 min	Rapid increase in the "total index of intoxication": strong bradycardia within 1 min, profound changes in ECG within 20 min, pulmonary infarctions and edema, blood acidosis and elevated pO_2, and EEG changes near the time of death (at 60 min).	Richard et al. (1978b) B-10
NH_3 4,320 (6,000)	Not given	Artificial respiration of curarized animals	"Fauve de Bourgogne" rabbits, avg. wt 2.5 kg	Unknown no. of M (perhaps just 1)	Served as own controls	60 min	180 min	Increased "total index of intoxication" during exposure, rapid increase after exposure: immediate and strong bradycardia, changes in ECG, increased blood pressure, pulmonary infarctions and edema, elevated pO_2, blood acidosis, and changes in EEG near time of death.	Richard et al. (1978b) B-10

(continued)

TABLE III-12. (continued)

Compound(s) and Concentration(s) in mg/m³ (ppm)		Humidity	Mode of Exposure	Species/ Strain/ Age/Weight	No. of Test Animals	No. of Controls	Duration & Frequency of Exposure	Total Length of Expt.	Effects	Reference and Rating
NH_3	3,600 (5,000)	Not given	Artificial respiration of curarized animals	"Fauve de Bourgogne" rabbits, avg. wt 2.5 kg	Unknown no. of M (perhaps just 1)	Served as own controls	60 min	180 min	Increase in the "total index of intoxication," remaining at that level during the recovery period: foam in the trachea and bronchial tree, zones of infarction, acute pulmonary edema, bradycardia, arrhythmia, extrasystoles, changes in blood pressure, and blood acidosis.	Richard et al. (1978b) B-10
NH_3	1,858-3,312 (2,580-4,600)	Not given	Well-ventilated chamber	Rabbits	19	0	10 h	-	Symptoms about the same as at 1,642-1,800 mg/m³. Respiration 12-15. Cornea clear although the eyes were mostly open. Killed with $CHCl_3$ 24 h after exposure. Many fine hemorrhages in the tracheal mucosa. The tracheal epithelia was partially destroyed, voluminous purulent mucous tracheal exudate. Numerous ecchymoses (extravasations of blood under the skin) and large anectatic (undilated?) regions in the lung.	Lehmann (1886) B-9
NH_3	2,160 (3,000)	Not given	Artificial respiration of curarized animals	"Fauve de Bourgogne" rabbits, avg. wt 2.5 kg	Unknown no. of M (perhaps just 1)	Served as own controls	60 min	180 min	Increase in the "total index of intoxication." Little apparent recovery by 90 min. Foam in the trachea. Bradycardia, arrhythmia, and extrasystoles.	Richard et al. (1978b) B-10
NH_3	1,634-1,872 (2,270-2,600)	Not given	Well-ventilated chamber	Rabbits	17	0	8.33 h once	-	Slight symptoms. Respiration 18-26. Cornea slightly cloudy. Ate immediately after test.	Lehmann (1886) B-9

(continued)

TABLE III-12. (concluded)

Compound(s) and Concentration(s) in mg/m³ (ppm)	Humidity	Mode of Exposure	Species/ Strain/ Age/Weight	No. of Test Animals	No. of Controls	Duration & Frequency of Exposure	Total Length of Expt.	Effects	Reference and Rating
NH_3 1,800 (2,500)	Not given	Artificial respiration of curarized animals	"Fauve de Bourgogne" rabbits, avg. wt 2.5 kg	Unknown no. of M (perhaps just 1)	Served as own controls	60 min	180 min	Increase in the "total index of intoxication." Little apparent recovery by 90 min. Early bradycardia, often accompanied by arrhythmia and extrasystoles.	Richard et al. (1978b) B-10
NH_3 1,642-1,800 (2,280-2,500)	Not given	Well-ventilated chamber	Rabbits	12	0	2.5 h once	-	Some symptoms of irritation. Tearing. After 1 h, some salivary secretion began, which persisted a long time. Some milky secretions from the eye.	Lehmann (1886) B-9
NH_3 893-1,037 (1,240-1,440)	Not given	Well-ventilated chamber	Rabbit	45	0	7 h once	-	Slight symptoms. Respiration fell from 78 to 25-32. Normal after exposure.	Lehmann (1886) B-9
NH_3 576-770 (800-1,070)	Not given	Well-ventilated chamber	Rabbits	5	0	7 h once	-	Slight symptoms. Respiration [sic] before the test 100-140 fell successively to 25. Some salivary secretion.	Lehmann (1886) B-9
NH_3 720 (1,000)	Not given	Artificial respiration of curarized animals	"Fauve de Bourgogne" rabbits, avg. wt 2.5 kg	Unknown no. of M (perhaps just 1)	Served as own controls	60 min	180 min	An increase in the "total index of intoxication." No discussion of individual effects. Some recovery by 90 min.	Richard et al. (1978b) B-10

TABLE III-13. RABBITS—REPEATED DOSE EXPERIMENTAL EXPOSURE TO NH_3

Compound(s) and Concentration(s) in mg/m³ (ppm)		Humidity	Mode of Exposure	Species/ Strain/ Age/Weight	No. of Test Animals	No. of Controls	Duration & Frequency of Exposure	Total Length of Expt.	Effects	Reference and Rating
NH_3	770 ± 55 (1,070)	50%	Modified Rochester-type inhalation chamber	New Zealand Albino rabbits	3 M	12 M	8 h/d, 5 d/wk, 6 wk	6 wk	No deaths. Mild to moderate dyspnea and lacrimation during the first week, disappearing during the second week. No further indications of toxicity or irritation were noted at necropsy or during hematological and histopathological exam, attributable to NH_3.	Coon et al. (1970) B-12
NH_3	155 ± 32 (215)	50%	Modified Rochester-type inhalation chamber	New Zealand Albino rabbits	3 M	12 M	8 h/d, 5 d/wk, 6 wk	6 wk	No deaths, visible signs of toxicity, or gross tissue abnormalities. Hematological values normal.	Coon et al. (1970) B-12
NH_3	72 (100)	Not given	Constant temperature chamber	New Zealand White rabbits	7 F	Served as own controls (values obtained immediately after exposure included)	2.5-3 h (the second of 3 consecutive equal time periods)	7.5-9 h (Expt. repeated 43 times at unknown intervals)	Significant 67% decrease in respiration rate. Possibly increased depth of respiration (indirectly measured). Periodicity of respiratory volume changes not affected. No histopathological changes found.	Mayan and Merilan (1972) B-11
NH_3	36 (50)	Not given	Constant temperature chamber	New Zealand White rabbits	9 F	Served as own controls (values obtained immediately after exposure included)	2.5-3 h (the second of 3 consecutive equal time periods)	7.5-9 h (Expt. repeated 33 times at unknown intervals)	Significant 34% decrease in respiration rate. No change in the periodicity of relative changes in respiratory volume. Perhaps an increase in the depth of respiration (indirectly measured).	Mayan and Merilan (1972) B-11

TABLE III-14. RABBITS—CHRONIC EXPERIMENTAL EXPOSURE TO NH_3

Compound(s) and Concentration(s) in mg/m³ (ppm)	Humidity	Mode of Exposure	Species/ Strain/ Age/Weight	No. of Test Animals	No. of Controls	Duration & Frequency of Exposure	Total Length of Expt.	Effects	Reference and Rating
NH_3 470 ± 16 (653)	50%	Modified Rochester-type inhalation chamber	New Zealand Albino rabbit	3 M	12 M	Continuous 90 d	90 d	No deaths. Marked eye irritation: heavy lacrimation and erythema, discharge, and opacity over 1/4 to 1/2 of the cornea. Moderate lung congestion in 2/3. No difference in hematological values. Histopathological examination revealed focal or diffuse interstitial pneumonitis in all animals. Other histopathological changes seen in the heart, liver, kidneys, and bronchi, with similar but lesser changes in the control group.	Coon et al. (1970) B-12
NH_3 40 ± 2 (56)	50%	Modified Rochester-type inhalation chamber	New Zealand Albino rabbit	3 M	12 M	Continuous 114 d	114 d	No death or signs of toxicity in any of the animals. Necropsy observations were normal.	Coon et al. (1970) B-12

TABLE III-15. CATS--ACUTE EXPERIMENTAL EXPOSURE TO NH_3

Compound(s) and Concentration(s) in mg/m^3 (ppm)	Humidity	Mode of Exposure	Species/ Strain/ Age/Weight	No. of Test Animals	No. of Controls	Duration & Frequency of Exposure	Total Length of Expt.	Effects	Reference and Rating
NH_3 893-1,037 (1,240-1,440)	Not given	Well-ventilated chamber	Cats	44	0	7 h once	-	Nose bleeds. Eyes remained clear. Killed immediately after the expt. with $CHCl_3$. Suppurative tracheitis, lungs hyperemic with 6-8 fine ecchymoses.	Lehmann (1886) B-9
NH_3 590-1,030 (820-1,430)	Not given	Well-ventilated chamber	Cats	6	0	5.5 h once	-	Symptoms of irritation stronger than when exposed to 800 to 1,070 ppm (576-770 mg/m^3). Respiration slowed (7-9), dyspneic. Distinct evidence of pain. After exposure, some nasal catarrh, which cleared up very quickly.	Lehmann (1886) B-9
NH_3 576-770 (800-1,070)	Not given	Well-ventilated chamber	Cats, half-grown	4	0	7 h once	-	Slight symptoms of irritation, interruption of motion, persistent salivary secretion of variable consistency. Respiration 12-20. After exposure, the salivary secretion continued for 2 h and then was normal.	Lehmann (1886) B-9
NH_3 720 (1,000)	Not given	Head exposure plethysmograph chamber	Stray, mixed breed cats	20	2, for pathological changes only. Served as own controls otherwise.	10 min	35 d	All suffered severe dyspnea, anorexia, and dehydration. 1/20 died of bronchopneumonia. Pulmonary function tests indicate 2 stages of dysfunction: acute and chronic. Good correlation between function data and pathological lesions found.	Dodd and Gross (1980) B-11
NH_3 346-410 (480-570)	Not given	Well-ventilated chamber	Cat	1	0	4 h once	-	Some symptoms of irritation from the beginning, secretion of saliva, retarded respiration. Then normal behavior, very quiet. Then at the end of the expt. again highly fluid salivary secretion. No symptoms of harm after the test.	Lehmann (1886) B-9

TABLE III-16. MONKEYS--REPEATED DOSE EXPERIMENTAL EXPOSURE TO NH_3

Compound(s) and Concentration(s) in mg/m^3 (ppm)	Humidity	Mode of Exposure	Species/ Strain/ Age/Weight	No. of Test Animals	No. of Controls	Duration & Frequency of Exposure	Total Length of Expt.	Effects	Reference and Rating
NH_3 770 ± 55 (1,070)	50%	Modified Rochester-type inhalation chamber	Squirrel monkeys (Saimiri sciureus)	3 M	8 M	8 h/d, 5 d/wk, 6 wk	6 wk	No deaths. No signs of irritation or toxicity were noted.	Coon et al. (1970) B-12
NH_3 155 ± 32 (215)	50%	Modified Rochester-type inhalation chamber	Squirrel monkeys (Saimiri scieureus)	3 M	8 M	8 h/d, 5 d/wk, 6 wk	6 wk	No deaths, visible signs of toxicity, or gross abnormalities in organs or tissues. Histopathological examination showed evidence of focal pneumonitis in the lung of 1 monkey.	Coon et al. (1970 B-12

TABLE III-17. MONKEYS--CHRONIC EXPERIMENTAL EXPOSURE TO NH_3

Compound(s) and Concentration(s) in mg/m³ (ppm)	Humidity	Mode of Exposure	Species/ Strain/ Age/Weight	No. of Test Animals	No. of Controls	Duration & Frequency of Exposure	Total Length of Expt.	Effects	Reference and Rating
NH_3 470 ± 16 (652)	50%	Modified Rochester-type inhalation chamber	Squirrel monkeys (*Saimiri sciureus*)	3 M	8 M	Continuous 90 d	90 d	No deaths. No change in hematological values. Focal or diffuse interstitial pneumonitis in all animals. Other histopathological changes seen in the heart, liver, kidneys, and bronchi, with similar but lesser changes in the control group.	Coon et al. (1970) B-12
NH_3 40 ± 2 (56)	50%	Modified Rochester-type inhalation chamber	Squirrel monkeys (*Saimiri sciureus*)	3 M	8 M	Continuous 114 d	114 d	No deaths or signs of toxicity in any of the animals. Necropsy observations were normal. Histopathological examination revealed lipid filled macrophages in the lung of 1 monkey. This finding was judged to be clinically insignificant.	Coon et al. (1970) B-12

TABLE III-18. DOGS--REPEATED DOSE EXPERIMENTAL EXPOSURE TO NH_3

Compound(s) and Concentration(s) in mg/m^3 (ppm)	Humidity	Mode of Exposure	Species/ Strain/ Age/Weight	No. of Test Animals	No. of Controls	Duration & Frequency of Exposure	Total Length of Expt.	Effects	Reference and Rating
NH_3 770 ± 55 (1,070)	50%	Modified Rochester-type inhalation chamber	Purebred beagle dog	2 M	12 M	8 h/d, 5 d/wk, 6 wk	6 wk	No deaths. Mild to moderate dyspnea and lacrimation during the first week, disappearing during the second week. No further signs of irritation or toxicity were noted at necropsy or hematological and histopathological exam, attributable to NH_3.	Coon et al. (1970) B-12
NH_3 155 ± 32 (215)	50%	Modified Rochester-type inhalation chamber	Purebred beagle dog	2 M	12 M	8 h/d, 5 d/wk, 6 wk	6 wk	No deaths, visible signs of toxicity, or gross tissue abnormalities. Hematological values normal.	Coon et al. (1970) B-12

TABLE III-19. DOGS--CHRONIC EXPERIMENTAL EXPOSURE TO NH_3

Compound(s) and Concentration(s) in mg/m³ (ppm)	Humidity	Mode of Exposure	Species/ Strain/ Age/Weight	No. of Test Animals	No. of Controls	Duration & Frequency of Exposure	Total Length of Expt.	Effects	Reference and Rating
NH_3 470 ± 16 (652)	50%	Modified Rochester-type inhalation chamber	Purebred beagle dog	2 M	12 M	Continuous 90 d	90 d	No deaths. No change in hematological values. Heavy lacrimation and nasal discharge noted. Hemorrhagic lesion in the lung of 1 dog. Focal or diffuse interstitial pneumonitis in all animals. Other histopathological changes seen in the heart, liver, kidneys and bronchi, with similar but lesser changes in the control group.	Coon et al. (1970) B-12
NH_3 40 ± 2 (56)	50%	Modified Rochester-type inhalation chamber	Purebred beagle dog	2 M	12 M	Continuous 114 d	114 d	No deaths or signs of toxicity in any of the animals. Necropsy observations were normal. Histopathologic examination revealed lipid filled macrophages in the lungs of both dogs. This was deemed to be of no clinical significance.	Coon et al. (1970) B-12

TABLE III-20. TURKEYS--REPEATED DOSE EXPERIMENTAL EXPOSURE TO NH_3

Compound(s) and Concentration(s) in mg/m^3 (ppm)	Humidity	Mode of Exposure	Species/ Strain/ Age/Weight	No. of Test Animals	No. of Controls	Duration & Frequency of Exposure	Total Length of Expt.	Effects	Reference and Rating
NH_3 72 (100)	10-30%	Cabinet (336 ft^3)	Bronze turkeys, 4 wk			Continuous (all animals previously exposed to 13 d of 36 mg/m^3)	18 d	Gradually increasing pulmonary edema, congestion, and hemorrhage. Turkeys also exhibited anorexia and slow weight gains.	Anderson et al. (1964) B-12
				2	3	1 d			
				2	3	3 d			
				2	3	5 d			
NH_3 36 (50)	10-30%	Cabinet (336 ft^3)	Bronze turkeys, 4 wk			Continuous	12 d	Gradually increasing pulmonary congestion, edema, and hemorrhage. Turkeys also exhibited anorexia and slow weight gain.	Anderson et al. (1964) B-12
				2	3	10 d			
				2	3	12 d			
NH_3 36 (50)	10-30%	Cabinet (336 ft^3)	Bronze turkeys, 4 wk	2	3	Continuous 2 d (after 6 d exposure to 14.4 mg/m^3)	8 d	Nothing significant.	Anderson et al. (1964) B-12
NH_3 14.4-21.6 (20-30) Dust 0.6-1.0 mg/ft^3	~ 40-85%	Growth chambers	Broadwhite turkeys, 2 wk	600 M 600 F (3 expts. with 400 turkeys each)	Apparently none	10 wk, continuous, with turkeys removed every 2 wk for autopsy	2 wk	Averaged 3.1% mortality for the 10-wk period, and 2.79 lb of feed/lb of turkey (feed conversion) at 12 wk. No difference from the other treatments done. Histopathological changes in the respiratory tract seen. The 16.2% airsacculitis was due to the high dust level, not the NH_3 level. No interaction was seen between the dust and the NH_3.	Anderson et al. (1968) B-13

(continued)

TABLE III-20. (continued)

Compound(s) and Concentration(s) in mg/m³ (ppm)	Humidity	Mode of Exposure	Species/ Strain/ Age/Weight	No. of Test Animals	No. of Controls	Duration & Frequency of Exposure	Total Length of Expt.	Effects	Reference and Rating
NH_3 14.4-21.6 (20-30) Dust 0.1-0.4 mg/ft³	~ 40-85%	Growth chambers	Broadwhite turkeys, 2 wk	600 M 600 F (3 expts. with 400 turkeys each)	Apparently none	10 wk, continuous, with turkeys removed every 2 wk for autopsy	12 wk	Averaged 3.6% mortality in the 10 wk period and 2.73 lb of feed/lb of turkey (feed conversion) at wk 12, with no significant differences from other treatments done. Histopathological changes in the respiratory tract seen. The 11.0% air sacculitis is low, due to the low dust level. No interaction between dust and NH_3.	Anderson et al. (1968) B-13
NH_3 14.4 (20)	10-30%	Cabinet (336 ft³)	Bronze turkeys, 4 wk	2	3	Continuous 1 d	6 d	Exposure for 1 d increased mucous secretion from the upper respiratory tract, symptoms disappearing in 3-4 d. No other effect.	Anderson et al. (1964) B-12
				2	3	2 d			
				2	3	4 d			
				2	3	6 d			
NH_3 0-5.8 (0-8) Dust 0.6-1.0 mg/ft³ (both increased gradually with time, and fluctuated, generally stable by wk 8)	~ 40-85%	Growth chambers	Broadwhite turkeys, 2 wk	600 M 600 F (3 expts. with 400 turkeys each)	Apparently none	10 wk, continuous, with turkeys removed every 2 wk for autopsy	12 wk	Averaged 3.2% mortality for the 10-wk period, and 2.84 lb of feed/lb of turkey (feed conversion) at wk 12. No differences from other treatments done. Histopathological changes in the respiratory tract. Averaged 18.2% airsacculitis, due to high dust levels, not the NH_3. No interaction between dust and NH_3.	Anderson et al. (1968) B-13
NH_3 0-5.8 (0-8) Dust 0.1-0.4 mg/ft³	~ 40-85%	Growth chambers	Broadwhite turkeys, 2 wk	600 M 600 F (3 expts. with 400 turkeys each)	Apparently none	10 wk, continuous, with turkeys removed every 2 wk for autopsy	12 wk	Averaged 3.6% mortality in the 10 wk period, and 2.74 lb of feed/lb of turkey (feed conversion) at wk 12. No differences from the other treatments. Histopathological changes did not occur, even by wk 12. The 7.1% airsacculitis was the lowest of all the treatments.	Anderson et al. (1968) B-13

TABLE III-21. SWINE--ACUTE EXPERIMENTAL EXPOSURE TO NH_3

Compound(s) and Concentration(s) in mg/m³ (ppm)	Humidity	Mode of Exposure	Species/ Strain/ Age/Weight	No. of Test Animals	No. of Controls	Duration & Frequency of Exposure	Total Length of Expt.	Effects	Reference and Rating
NH_3 54 (75) Exposed to an aerosol of a nonpathogenic strain of *E. coli* immediately before NH_3 exposure.	Not given	Exposure chamber	Conventional crossbred pigs, avg. age 6.2 d	40	40 (also exposed to nonpathogenic *E. coli* aerosol)	2 h	2+ h	Test animals had 75% more viable bacteria in their lungs than did the control animals.	Drummond et al. (1978) B-10
NH_3 36 (50) Exposed to an aerosol of a nonpathogenic strain of *E. coli* immediately before NH_3 exposure.	Not given	Exposure chamber	Conventional crossbred pigs, avg. age 15.5 d	40	40 (also exposed to nonpathogenic *E. coli* aerosol)	2 h	2+ h	Test animals had 46% more viable bacteria in their lungs than did the controls. Increased lung weight and lung weight-body weight ratio. No gross or histopathological changes.	Drummond et al. (1978) B-10

TABLE III-22. SWINE--REPEATED DOSE EXPERIMENTAL EXPOSURE TO NH_3

Compound(s) and Concentration(s) in mg/m³ (ppm)	Humidity	Mode of Exposure	Species/ Strain/ Age/Weight	No. of Test Animals	No. of Controls	Duration & Frequency of Exposure	Total Length of Expt.	Effects	Reference and Rating
NH_3 ~ 200.6 (~ 280)	Not given	Environmental chamber	Gilt (young female swine), 30 kg	1 F	None	36 h	43 h	Immediate frothing of the mouth, lasting 3 h. Secretions of the mouth and nose, short and irregular breathing, sneezing and headshaking persisted. Convulsions by 36 h. Apparent return to normal 7 h after exposure stopped.	Stombaugh et al. (1969) B-11
NH_3 avg. 104.4 (145)	77%	Environmental chamber (with wastes removed daily)	Duroc pigs, avg. wt 54 kg	18	Apparently none	5 wk	5 wk	Feed consumption at the level of the 103 ppm group, and below that of the 12 and 61 ppm groups. Avg. daily gain fluctuated in relationship to other groups. Feed conversion not affected. Nasal, lacrimal, and mouth secretions decreasing with time. Increased cough rate.	Stombaugh et al. (1969) B-11
NH_3 76.6 (106.4) Corn starch dust (3-5 μm) 213 mg/m³	19-47%	Environmental chamber (with removal of wastes)	Yorkshire Landrace pigs, 1 wk	6	6 (chamber air had 8.9 ppm NH_3)	1-5 wk	5 wk	Conjunctivitis began the first day, and lasted 2 wk. No clinicopathological or microbiological changes. No epithelial thickening, or decrease in goblet cell number. Difference in effects from NH_3 alone possibly due to gas absorption onto the particles, and removal in the nasal passages.	Doig and Willoughby (1971) B-11
NH_3 76.6 (106.4) Ground corn dust (3-5 μm) 10.6 mg/m³	19-47%	Environmental chamber (with removal of wastes)	Yorkshire Landrace pigs, 1 wk	6	6	1-5 wk	5 wk	Slight conjunctivitis during the first wk. No tracheal or turbinate epithelial thickening. Decrease in epithelial goblet cell number, similar to that of NH_3 alone.	Doig and Willoughby (1971) B-11

(continued)

TABLE III-22. (continued)

Compound(s) and Concentration(s) in mg/m^3 (ppm)	Humidity	Mode of Exposure	Species/ Strain/ Age/Weight	No. of Test Animals	No. of Controls	Duration & Frequency of Exposure	Total Length of Expt.	Effects	Reference and Rating
NH_3 76.6 (106.4)	19-47%	Environmental chamber (with removal of wastes)	Yorkshire Landrace pigs, 1 wk	6	6 (chamber air had 8 ppm NH_3)	1-6 wk	6 wk	Slight conjunctivitis during the first wk. No clinicopathologic or microbiologic changes. Some subpleural hemorrhage and lobular atelectasis in both test and control groups. Tracheal and turbinate epithelia had increased thickness and decreased numbers of goblet cells. No lower respiratory tract changes, indicating high NH_3 removal in the upper tract. No weight loss.	Doig and Willoughby (1971) B-11
NH_3 avg. 74.2 (103)	77%	Environmental chamber (with wastes removed daily)	Duroc pigs, avg. wt. 54 kg	18	Apparently none	5 wk	5 wk	Feed consumption lower than that for the 12 and 61 ppm groups, and about equal to that of the 145 ppm group. Avg. daily gain varied in relationship to other groups. Feed conversion not affected. Nasal, lacrimal, and mouth secretions decreasing with time. Increase in cough rate.	Stombaugh et al. (1969) B-11
NH_3 avg. 43.9 (61)	77%	Environmental chamber (with waste removed daily)	Duroc pigs, avg. wt. 54 kg	18	Apparently none	5 wk	5 wk	Feed consumption slightly below that of pigs exposed to 12 ppm, and above the 103 and 145 ppm groups. Avg. daily gain varied in relationship to the other groups. Feed conversion was unaffected.	Stombaugh et al. (1969) B-11
NH_3 54 (75)	Not given	Exposure chamber	Crossbred pigs, avg. wt. 9.1 kg	8	8	46, 78, or 109 d	109 d	No effect on mean daily bodyweight gain. No changes in respiratory-tract structure.	Curtis et al. (1975) B-12

(continued)

TABLE III-22. (continued)

Compound(s) and Concentration(s) in mg/m³ (ppm)	Humidity	Mode of Exposure	Species/Strain/Age/Weight	No. of Test Animals	No. of Controls	Duration & Frequency of Exposure	Total Length of Expt.	Effects	Reference and Rating
NH_3 36 (50) and Dust 300 mg/m³	Not given	Exposure chamber	Crossbred pigs	12	12	24, 57, or 71 d	71 d	Decreased mean daily body-weight gain. No effect on respiratory-tract structure.	Curtis et al. (1975) B-12
NH_3 36 (50) and Dust 10 mg/m³	Not given	Exposure chamber	Crossbred pigs, avg. wt. 8.2 kg	4	4	27 d	27 d	No effect on mean daily body-weight gain. No changes in respiratory-tract structure.	Curtis et al. (1975) B-12
NH_3 36 (50) and H_2S 2.8 (2)	Not given	Exposure chamber	Crossbred pigs, avg. wt. 20.9 kg	3	3	19 d	19 d	No effect on mean daily body-weight gain. No changes in respiratory-tract structure.	Curtis et al. (1975) B-12
NH_3 36 (50)	Not given	Exposure chamber	Crossbred pigs, avg. wt. 8.2-31.8 kg	16	16	24-71 d	71 d	No effect on mean daily body-weight gain. Mild conjunctivitis and blepharitis in 1/16. No changes in respiratory-tract structure.	Curtis et al. (1975) B-12
NH_3 avg. 8.6 (12)	77%	Environmental chambers (with waste removed daily)	Duroc pigs, avg. initial wt. 54 kg	18	Apparently none	5 wk	5 wk	Feed consumption slightly higher than pigs exposed to 50 ppm, and above that of pigs exposed to 100 or 150 ppm. Avg. daily gain varied with time in relationship to other exposures. No effect on feed conversion.	Stombaugh et al. (1969) B-11

SECTION IV

EXPERIMENTAL HUMAN INHALATION EXPOSURES

Tables IV-1 and IV-2 describe acute and repeated dose laboratory human exposures to NH_3, respectively. Table S-2 in the summary condenses all the information regarding experimental human exposure, from about 40 mg/m^3 to < 0.5 mg/m^3. The American Conference of Governmental Industrial Hygienists gives 18.0 mg/m^3 as the time-weighted-average threshold limit value and 27 mg/m^3 as the short-term-exposure limit (ACGIH, 1981).

TABLE IV-1. HUMANS--ACUTE EXPERIMENTAL INHALATION EXPOSURE TO NH_3

Compound(s) and Concentration(s) in mg/m³ (ppm)	Mode of Exposure	No. of Test Subjects	No. of Controls	Duration and Frequency of Exposures	Total Length of Expt.	Effects	Reference and Rating
NH_3 381.6-403.2 (530-560)	Room (unspecified)	1 M	Served as own control	4 h, once	7 h	The levels of nonprotein nitrogen and NH_3 in the blood plasma increased with increasing exposure time. The urea and creatinine content of the blood showed no change from normal values. The carbon dioxide-combining power of the blood plasma was not impaired. Pulse rate was constant, and blood pressure (probably systolic) decreased in the first 35 min of inhalation.	Schmidt and Vallencourt (1948) B-8
NH_3 360 (500)	Mask over nose and mouth	7 M	Served as own controls	30 min, once	45-60 min	Expired air ammonia at equilibrium varied from 252 to 346 mg/m³, occurring from 10 to 27 min after exposure began. Respiratory rate was slightly elevated, and minute volume increased from 50 to 250% over that of control levels, both parameters quickly returning to normal after exposure ended. Lung ventilation showed a cyclic variation during exposure in 2/7. No coughing was induced. Reflexly induced lacrimation occurred in 2/7. Subjective reactions varied widely.	Silverman et al. (1949) A-11
NH_3 avg. 235; range 180-344, increasing with exposure time	Exposure chamber (with oro-nasal mask and 3-way valve box during exercise)	18 M (with ~ 60 min preceding exposure to 72-122 mg NH_3/m³)	Served as own controls on days 1 and 3 of experiment	35-60 min, once, on day 2 of experiment. Included an 8-min exercise period.	Three consecutive 0.5-d sessions	Increased exercise cardiac frequency and respiratory frequency. Decreased ventilation minute volume and exercise tidal volume. No material discomfort.	Cole et al. (1977) B-11

(continued)

TABLE IV-1. (continued)

Compound(s) and Concentration(s) in mg/m^3 (ppm)	Mode of Exposure	No. of Test Subjects	No. of Controls	Duration and Frequency of Exposures	Total Length of Expt.	Effects	Reference and Rating
NH_3 avg. 144; range 115-158, increasing with exposure time	Exposure chamber (with oro-nasal mask and 3-way valve box during exercise)	18 M (with ~ 60 min preceding exposure to 115-158 mg NH_3/m^3, as near as can be determined from the methodology given)	Served as own controls on days 1 and 3 of experiment	35-60 min, once, on day 2 of experiment. Included an 11-min exercise period.	Three consecutive 0.5 d sessions	Slight decrease in exercise cardiac frequency. Significantly reduced ventilation minute volume due to reduced tidal volume, despite a significant increase in respiratory frequency. No material discomfort.	Cole et al. (1977) B-11
NH_3 avg. 106; range 72-122, increasing with exposure time	Exposure chamber (with oro-nasal mask and 3-way valve box during exercise)	18 M	Served as own controls on days 1 and 3 of experiment	35-60 min, once, on day 2 of experiment. Included an 8-min exercise period.	Three consecutive 0.5 d sessions	Significant increases in exercise cardiac frequency and exercise tidal volume. Decreased ventilation minute volume due to a slightly reduced respiratory frequency. No material discomfort.	Cole et al. (1977) B-11
NH_3 100.8 (140)	Exposure chamber (25 m^3)	7 M 1 F "experts" 6 M 2 F "nonexperts"	Served as own controls	2 h, once		$< 10\%$ decrease in VC, FEV_1, and $\bar{F}IV_1$. No hypersusceptibility to nonspecific irritants, as measured by the histamine threshold. Strong eye and throat irritation, with cough, in the "nonexperts," becoming unbearable so 8/8 had to leave before 2 h. "Experts" had perceptible eye and throat irritation, with slight cough.	Verberk (1977) A-13
NH_3 96.48 (134)	Inhalation chamber (700 L) (head only)	8 M 2 F		5 min, once		10/10 detected the odor. 5-8/10 reported lacrimation and irritation to the eyes, nose, mouth, or throat. 1/10 reported slight irritation to the chest.	Keplinger et al. (1973) A-12
NH_3 79.2 (110)	Exposure chamber (25 m^3)	7 M 1 F "experts" 6 M 2 F "nonexperts"	Served as own controls	2 h, once		$< 10\%$ decrease in VC, FEV_1, and $\bar{F}IV_1$. No hypersusceptibility to nonspecific irritants, as measured by the histamine threshold. Definite eye irritation, perceptible throat irritation, slight cough. "Nonexperts" generally more uncomfortable than "experts."	Verberk (1977) A-13

(continued)

TABLE IV-1. (continued)

Compound(s) and Concentration(s) in mg/m^3 (ppm)	Mode of Exposure	No. of Test Subjects	No. of Controls	Duration and Frequency of Exposures	Total Length of Expt.	Effects	Reference and Rating
NH_3 avg. 71; range 50-79, increasing with exposure time	Exposure chamber (with oronasal mask and 3-way valve box during exercise)	18 M	Served as own controls on days 1 and 3 of experiment	35-60 min, once, on second day of experiment	3 consecutive 0.5 d sessions	Exercise cardiac frequency was reduced. No effect on ventilation minute volume, exercise tidal volume, or mean respiratory frequency. No material discomfort.	Cole et al. (1977) B-11
NH_3 57.6 (80)	Exposure chamber (25 m^3)	7 M 1 F "experts" 6 M 2 F "nonexperts"	Served as own controls	2 h, once		< 10% decrease in VC, FEV_1, and FIV_1. No hypersusceptibility to nonspecific irritants, as measured by histamine threshold. Definite eye and slight throat irritation. Generally, "nonexperts" more uncomfortable.	Verberk (1977) A-13
NH_3 51.84 (72)	Inhalation chamber (700 L) (head only)	8 M 2 F		5 min, once		10/10 detected the odor. 2/10 had slight eye irritation. 1/10 had slight eye irritation, and dry nose and mouth. 1/10 had dry mouth. 1/10 had dry nose and mouth.	Keplinger et al. (1973) A-12
NH_3 36 (50)	Exposure chamber (25 m^3)	7 M 1 F "experts" 6 M 2 F "nonexperts"	Served as own controls	2 h, once		No change in VC, FEV_1, or FIV_1 of more than 10% after exposure. No hypersusceptibility to nonspecific irritants, as measured by histamine threshold. Odor was detected. Some slight eye and throat irritation.	Verberk (1977) A-13
NH_3 36 (50)	Inhalation chamber (700 L) (head only)	8 M 2 F		5 min, once		10/10 detected the odor. No significant signs of irritation (subjective evaluation).	Keplinger et al. (1973) A-12
NH_3 36 (50)	Rochester chamber, head exposure only	6 M	Served as own controls	10 min		4/6 described moderate eye and nasal irritation. 1/6 described a faint nonpainful irritation. 1/6 had no irritation. All described a strong, highly penetrating odor.	MacEwen et al. (1970) C-8

(continued)

TABLE IV-1. (concluded)

Compound(s) and Concentration(s) in mg/m³ (ppm)	Mode of Exposure	No. of Test Subjects	No. of Controls	Duration and Frequency of Exposures	Total Length of Expt.	Effects	Reference and Rating
NH_3 33.7 (46.8)	Exposure chamber	4		Not given, once		Odor threshold, the lowest concentration at which all 4 panelists recognized the odor.	Leonardos et al. (1969) A-11
NH_3 23 (32)	Inhalation chamber (700 L) (head only)	8 M 2 F		5 min, once		9/10 detected the odor. No significant signs of irritation (subjective evaluation).	Keplinger et al. (1973) A-12
NH_3 21.6 (30)	Rochester chamber, head exposure only	5 M	Served as own controls	10 min		2/5 felt faint, nonpainful nasal and eye irritation, and described moderate odor intensity. 3/5 detected no irritation and described a strong, highly penetrating odor.	MacEwen et al. (1970) C-8
NH_3 13	Exposure chamber (5 m³)	6 M	5 M	8 h	~24 h	Immediately after exposure, 50-100% increase in NH_3 and urea levels in urine, and NH_3 levels in blood. Significant decrease in O_2 consumption by 20%. Insignificant changes in EKG, and no change in arithmetic ability. Any changes observed were gone by the day after exposure.	Mikhailov et al. (1969) C-8
NH_3 3	Exposure chamber (5 m³)	6 M	5 M	8 h	~24 h	Immediately after exposure, no changes in NH_3 levels in blood and urine, urea levels in urine, or ability to make arithmetical calculations. Tendency to decrease the coefficient of O_2 consumption. Insignificant changes in EKG. Any changes observed were gone the day after exposure.	Mikhailov et al. (1969) C-8
NH_3 0.45 - 1.0	Not given	22		Not given	Not given	Thresholds of ammonia perception determined: 1.0 mg/m³ for 2/22, 0.75 mg/m³ for 7/22, 0.55 mg/m³ for 9/22, and 0.45 mg/m³ for 4/22	Sayfutdinov (1968) B-7

TABLE IV-2. HUMANS--REPEATED DOSE EXPERIMENTAL INHALATION EXPOSURE TO NH_3

Compound(s) and Concentration(s) in mg/m^3 (ppm)	Mode of Exposure	No. of Test Subjects	No. of Controls	Duration and Frequency of Exposures	Total Length of Expt.	Effects	Reference and Rating
NH_3 regime: week concn. 1 18 2 36 3 72 4 18 5 36 6 72	Industrial work station (ammonium bicarbonate plant with slight artificial NH_3 enrichment)	2 M	Appeared to serve as own controls during a 1-3 d nonexposure period in the middle of the test.	3 h, twice a day, 5 d/wk, 6 wk	6 wk	Statistically significant increase in FEV_1 with increased NH_3 concentration. No change in respiration, pulse, blood pressures, or FVC. As observed by a physician, mild irritation of the eye, nose, or throat was nonexistent for weeks 4 and 5, and not statistically different from the no-exposure periods for week 6. Brief excursions to 144 mg/m^3 during weeks 2 and 6 caused only 1 case of increased irritation. All subjects reported some watering of the eyes and dryness of the nose and throat.	Ferguson et al. (1977) A-11
NH_3 regime: week concn. 1 72 2 36 3 18 4 18 5 36 6 72	Industrial work station (ammonium bicarbonate plant with slight artificial NH_3 enrichment)	2 M	Appeared to serve as own controls during a 1-3 d nonexposure period in the middle of the test.	3 h, twice a day, 5 d/wk, 6 wk	6 wk	Slight increase in FEV_1 with increased NH_3. As observed by a physician, mild eye, nose and throat irritation decreased after week 2, to control levels. No change in respiration, pulse, blood pressures or FVC. Brief excursions to 144 mg/m^3 during weeks 2 and 6 caused some watering of the eyes and dryness of nose and throat, and no increase of physician-observed irritation.	Ferguson et al. (1977) A-11
NH_3 36 (50)	Industrial work station (ammonium bicarbonate plant with slight artificial NH_3 enrichment)	1 F 1 M	Appeared to serve as own controls during a 1-3 d nonexposure period in the middle of the test.	3 h, twice a day, 5 d/wk, 6 wk	6 wk	No significant changes in perspiration, pulse, systolic and diastolic blood pressures, FVC, FEV_1, or rate of mild eye irritation were found at any time. No abnormalities of the chest, vital organs, neurological response, or significant weight changes were found.	Ferguson et al. (1977) A-11

(continued)

TABLE IV-2. (continued)

Compound(s) and Concentration(s) in mg/m^3 (ppm)	Mode of Exposure	No. of Test Subjects	No. of Controls	Duration and Frequency of Exposures	Total Length of Expt.	Effects	Reference and Rating
NH_3 10.5 ± 0.85	NH_3 in air delivered at 15 L/min through a funnel in the "breathing zone"	26	Served as own controls	4 h (test repeated 3-4 times at unknown intervals)		Decrease in the rate of exhalation during pneumotachometry. Duration of the transient process of the heart rhythm during cardiointervalography grew by an average of 14.6%. Increased latent period of smell-motion reaction. Inhibition of the reduction of odor sensitivity after loading.	Mikhailuts (1977) B-9
NH_3 6.1 ± 0.71	NH_3 in air delivered at 15 L/min through a funnel in the "breathing zone"	19 people, 2-4 d after convalescence from acute diseases of the upper respiratory tract.	26 "practically healthy" people	4 h (tests repeated 2-4 times at unknown intervals)		In the test group, there were decreased odor thresholds for benzene, valerian, and camphor (in 55-67% of the cases), but with possible exhaustion of the "odor analyzer." Rate of forced inhalation and expiration decreased with an intensity of the transient process of the heart rhythm. Control group had decreased camphor thresholds by 12-16% of the time to the transient process, and no change in other indexes.	Mikhailuts (1977) B-9
NH_3 2.2 ± 0.39	NH_3 in air delivered at 15 L/min through a funnel in the "breathing zone"	19 people, 2-4 d after convalescence from acute diseases of the upper respiratory tract	26 "practically healthy" people	4 h (tests repeated 2-4 times at unknown intervals)		In the test group, there was a tendency to decrease the forced rate of inhalation and exhalation (in 57.1-69% of the observations), and a lowering of the odor threshold of camphor (in 71.4% of the observations). Control group had decreased threshold odor of camphor, but also a rapid reduction in odor sensitivity. Control group pneumotachometry and cardiointervalography were unchanged.	Mikhailuts (1977) B-9

(continued)

TABLE IV-2. (continued)

Compound(s) and Concentration(s) in mg/m^3 (ppm)	Mode of Exposure	No. of Test Subjects	No. of Controls	Duration and Frequency of Exposures	Total Length of Expt.	Effects	Reference and Rating
NH_3 2.16 ± 0.06 Original Russian document reported a concentration of 2.16 mg/cm^3; assumed to be a typographical error.	Hermetically sealed 6 m^3 chamber			35 d	38 d	No significant effect on the level of gas and energy metabolism and acid-base equilibrium. An insignificant increase in O_2 consumption. No changes in the morphological composition of the peripheral blood. NH_3 levels in blood and breath increased with the length of exposure. Urea concentration in the urine increased only on day 32. Inhibition of the oxidative-reductive processes, indicated by decreased blood catalase activity and increased acetone levels in the breath. All changes disappeard by the 3rd day post-exposure.	Savina et al. (1980) B-7
NH_3 0.32 - 0.65	Not given	3 (at least 1 female)	Served as own controls	40 min, (tests repeated 3 times at unknown intervals)		A concentration of 0.45 mg NH_3/m^3 lowered eye sensitivity to light in 2/3, while 0.32 mg/m^3 was inactive. In 1/3, the threshold odor perception concentration which affected eye sensitivity to light was 0.65 mg/m^3, and the subthreshold value was 0.5 mg/m^3.	Sayfutdinov (1968) B-7
NH_3 0.32 - 0.76	Not given	5	Served as own controls	12 min (tests repeated 3 times, at unknown intervals)	Not given	In 3/5 test persons whose odor threshold was 0.55 mg/m^3, cerebral cortical activity was affected by 0.35 mg/m^3, decreased in 2 and enhanced in 1. In the other 2/5, with odor thresholds of 0.76 mg/m^3, the "activity" concentration was 0.44 mg/m^3 and the subthreshold level was 0.32 mg/m^3.	Sayfutdinov (1968) B-7

SECTION V

EPIDEMIOLOGY

OCCUPATIONAL EXPOSURES

Data for occupational exposures to ammonia as shown in Table V-1 are not especially useful for deriving a range of concern for ammonia in automobile emissions because occupational exposures are higher, and so many other possibly toxic factors are present. Table S-3 in the Summary condenses the occupational exposure data.

ACCIDENTAL EXPOSURES

Data for exposures to NH_3 due to a wide variety of accidents are given in Table V-2. These are not very useful because of the unknown (but probably high) levels of ammonia encountered, but were included because the description of organs affected and symptoms caused may have some helpful suggestions.

TABLE V-1. STUDIES OF OCCUPATIONAL EXPOSURE TO AMMONIA

Compound(s) Concentration(s) mg/m^3 (ppm) Duration	Population Group			Description	Remarks	Reference and Rating
	Description	Exposed	Controls			
NH_3 3.6-144 (5-200) CO (2-200) CO_2 (800-10,000) H_2S 7.1-14.2 (5-10) 2-12 h/d 7 d/wk	Workers in swine confinement units	11	0	Over 50% complained of: coughing, increased sputum or phlegm, chest tightness, wheezing, stuffy nose, shortness of breath, or sneezing. Some eye irritation, headache, dizziness, nausea, and vomiting. Veterinarians surveyed had similar responses.	Confounding with other gases and dust. Gas concentrations varied with season, and no correlation made with possible variability in symptoms. Strictly descriptive study, no controls. Presence of seasonal variability demonstrates need for adequate control group. Numbers obviously too small for any inference to be drawn.	Donham et al. (1977) C-6
NH_3 50-75, with occasional levels above this for a short time. Asbestos (according to Bittersohl, 1971a). 80% of the employees worked for > 10 y.	Workers in plants producing or manufacturing ammonia.	Unknown no. out of 30,000 employees in the study.	Cancer statistics for the GDR	Cancer of the lungs, stomach, lymphatic tissue, and urinary tract was seen, accounting for 40-60% of all deaths. Cancer in NH_3 production plants exceeded that in other production plants by 5-6 times the rate of malignant tumors, and 15 times higher frequency of cancers than in the whole chemical factory. Male cancer rates per 10,000 employees generally higher than female cancer rates, probably due to longer employment times.	No mention of possible exposure to other compounds in the plants. The cancer rates were not age-adjusted, although differences between sexes were noted. Both articles are obviously about the same study, but the short summary article (Bittersohl, 1971b) does not mention asbestos. According to the other article, all production employees were exposed to asbestos, and those also exposed to NH_3 had the highest cancer rates, suggesting possible co-carcinogenicity.	Bittersohl (1971a) D-8 Bittersohl (1971b) C-6
NH_3 ~ 10-40 5-10 y	Workers in a NH_3 production plant.	45 M 28 F	55	At the end of the work day versus the beginning, subjective data showed an increase in headaches (27.56% versus 12.71%), vertigo 9.45% versus 3.4%), staggering (6.30% versus 3.06%), and tremors (24.26% versus 18.82%). Other signs of overexcitability of various nerve tracts were seen: anorexia, drowsiness, and forgetfulness.	Actually a descriptive study with poor utilization of internal controls. This type of comparison introduces strong interviewee bias. Beginning versus end-of-day data was not collected while the individuals were not exposed to NH_3 (i.e., off work or in different area). Could not determine the comparability of external controls. Exposure levels are not given and therefore not correlated with symptoms.	Kirkov (1977) C-5

(continued)

TABLE V-1. (continued)

Compound(s) Concentration(s) mg/m³ (ppm) Duration	Population Group			Description	Remarks	Reference and Rating
	Description	Exposed	Controls			
NH_3 5-29 Not given	Workers exposed to irritating dusts and gases.	143 M	67 M	Higher incidence of chronic bronchitis and dyspnea. Lower FEV_1 values in those workers. Occupational exposure to NH_3 to some degree connected with lowering of FEV_1 values.	Epidemiological design: Descriptive study relies on FEV_1 as relatively crude outcome measure. Internal controls are apparently utilized, but it is difficult to determine if they are comparable for relevant characteristics, i.e., age. Age, height weight are listed in appendix. Exposure variables are poorly defined, especially duration of exposure. Also true for confounding variables such as smoking. Only data on whether or not the workers ever smoked is utilized. Strongest point is that clinical systems can be related to FEV_1 measurements so that if exposure research could be refined, meaningful data could be obtained.	Kujawska et al. (1977) B-10
NH_3 ~ 18.3-26.3, H_2SO_4 aerosols unknown but apparently much less than NH_3 concentrations. Not given.	Workers in a cuprammonium rayon spinning mill.	50 M 30 F	56 M 14 F	24% had slight and 28% moderate impairments of lung function. Study done 3 y later, when NH_3 levels had decreased to ~ 12.3 mg/m³, showed a decrease to 13% with moderate impairment. No trends found with age, weight, smoking habits, or exposure duration.	Nonconcurrent/concurrent prospective design (retrospective cohort) using an appropriate control group. Stratification performed on both age and duration of exposure and reversibility of outcome measures. Numbers are relatively small to place much confidence in conclusion. However, correlation with decreased NH_3 levels is impressive and certainly valuable information in assessing levels of concern. Selection bias and comparability of controls is always a concern but cannot be assessed from the data given here.	Herrman and Viehrig (1979) A-9

(continued)

TABLE V-1. (continued)

Compound(s) Concentration(s) mg/m³ (ppm) Duration	Population Group Description	Exposed	Controls	Description	Remarks	Reference and Rating
NH_3 6-26 NO_x 12-61	Workers exposed to irritating dusts and gases.	216 M	67 M	Occupational exposure to dusts, NH_3 and NO_x was connected with the lowering of FEV_1 values, perhaps more so than NH_3 alone.	Confounding due to multiple gases and dusts present.	Kujawska et al. (1977) B-10
NH_3 exceeded 20 mg/m³ in 25.5% of 800 samples.	Workers in the main shops of tanneries	46	-	Variations in the diurnal curves for 8 physiological functions were seen, particularly in muscular endurance, mean pressure, and pulse, particularly towards the end of the day. Probably due to the manual labor involved.	Stricly descriptive study, primarily focused on diurnal variations in physiologic function. The study does not relate these changes to variations in NH_3 concentrations. In the absence of controls the meaning of these changes is not clear. Most helpful information is the absence of H_2S and the presence of NH_3, but SO_2 is variably present. Clinical measures (i.e., respiratory symptoms or respiratory functions) are not made.	Sinitsyna (1965) D-6
NH_3 generally < 20 NO_x, avg. < MAC (not given) 3 or 6 h/d for 2 y	Adolescents undergoing vocational training in a fertilizer factory or a chemical works.	300 (140 repeatedly)	85	At the end of 1 y, an 11% increase in the incidence of disorders of the upper respiratory tract, and a 27% increase in xeroderma. After 2 y, there were statistically significant increases of 24 and 36%, respectively. Changes in certain biochemical indexes indicated possible stress on hepatic functions.	Apparent concurrent prospective design comparing persons exposed to NH_3 and and NO_x to persons unexposed (training in different area of the same school). Comparability of the control group and methodology to prevent selection bias is not given. "Repeated examination" suggests period prevalence and not incidence data, but one cannot be certain. Although sample size is sufficient, appropriate point estimates are not made (i.e., relative risk) with confidence limits and acute versus chronic effects are not described. Rates based on exposure times would be possible, but are not given.	Giguz (1968) B-6

(continued)

TABLE V-1. (concluded)

Compound(s) Concentration(s) mg/m^3 (ppm) Duration	Population Group			Description	Remarks	Reference and Rating
	Description	Exposed	Controls			
NH_3, unknown, avg. exposure time of 16.1 y	Workers in an Egyptian ice factory.	41	28	Differences in lung function tests found, but perhaps due to differences in age and body size between the 2 groups. Differences in response to a chest symptomology questionnaire were considered insignificant after consideration of smoking habits.	This study is a poor attempt at a noncurrent prospective design. Numbers are insufficient for appropriate stratifications (i.e., age, smoking, habits, exposure variables, etc.) in the analysis. Either matching was not performed or a breakdown in age-matched groups occurred. (use of average age by group is not sufficient when small numbers are involved.) Conclusion of article is not valid. A lack of statistical significance does not demonstrate a lack of association (when small numbers are involved). The relative risk is 1.4 (20% versus 14%), but numbers are small and confidence limits are not given (see conclusion, pp. 309-310 of article). This difference would be likely to disappear with appropriate stratification on age and smoking habits.	El-Sewefy and Awad (1971) C-6
NH_3, unknown but probably very low to moderate, avg. 6.8 y of employment	Workers in a frozen food warehouse who routinely worked inside the freezer, where intermittent NH_3 leaks occurred.	19 M 1 F	-	Degree of discomfort ranged from severe nausea and headaches to mild throat and eye irritations. No serious injuries sought.	Only interviews were done. No physical or lung function exams. Descriptive study of acute affects of NH_3 toxicity, but there was a strong possibility for interviewee bias. No precautions were exercised to prevent this bias, and no control group was used.	Hollett (1977) C-7

TABLE V-2. HUMANS--STUDIES OF ACCIDENTAL EXPOSURES TO AMMONIA

Compound(s) and Concentration(s) in mg/m^3	Duration of Exposure	Accident Description(s)	No. of Accident Victims	Description	Reference and Rating
NH_3, unknown	Not given	Not given	2	Two victims with moderate intensity acute phase damage (burns to upper respiratory tract without apparent pulmonary involvement). One victim, at the end of 2 y, had pulmonary function values very close to the theoretical lower limits of normal, and normal blood gases. The other victim, followed for 1 y, had mixed ventilation difficulty of medium severity, and normal blood gases and exchanges.	Voisin et al. (1970) B-11
NH_3, unknown	Not given	Not given	2 M	Victims with medium clinical results in the acute phase (involvement of the upper respiratory tract). After 1.5 y, one victim had a restrictive ventilation problem of medium severity, and normal arterial blood gases. The other victim showed major mixed respiratory difficulties after one wk, and even 1 y later had significant ventilation difficulty with preponderant obstructive disease, increased residual volume, moderate hypoxemia, and decline in the pulmonary diffusing capacity of CO.	Voisin et al. (1970) B-11
NH_3, unknown	Not given	Not given	4 (at least 2 M)	Victims with major clinical results (parenchymatous effect is dominant, pulmonary edema extremely acute) in the acute phase. One victim showed a gradual deterioration of pulmonary functions over 4 y, the alteration of blood gas exchanges, and chronic bronchitis. A second victim showed respiratory insufficiency >1 y after exposure. A third victim showed ventilation problems of the mixed restrictive-obstructive type 1 y after exposure. There was pre-existing anthracosilicosis. The fourth victim, 1 y after exposure, had great ventilation difficulty of a mixed type with major obstructive involvement.	Voisin et al. (1970) B-11
NH_3, unknown, but high	< 1 min to a few minutes	Vent stack overflowed with pure liquid ammonia, dousing men 100 ft below	2 M	The victim with the shorter exposure had dyspnea, chest pain, blepharospasm, burning throat, extensive blisters, tachycardia, and moist sounds, both bases. Lung functions improved for 2 y, but still below normal after 5 y. The transfer factor is nearly normal. The more exposed victim lost consciousness, and suffered dyspnea, chest pain, blepharospasm, burning throat, blisters and sloughs of oral mucosa and exposed skin, conjunctivitis, and bronchitis. Later became a physical training teacher, with above normal lung functions.	Walton (1973) B-11

(continued)

TABLE V-2. (continued)

Compound(s) and Concentration(s) in mg/m^3	Duration of Exposure	Accident Description(s)	No. of Accident Victims	Description	Reference and Rating
NH_3, unknown, but high	< 1 min	Dismantling a valve on an ammonia high-pressure line.	1 M	Experienced blepharospasm and bronchospasm. Ventilation tests normal after 1 y, but transfer factor still depressed after 5 y, which could be associated with smoking.	Walton (1973) B-11
NH_3, unknown, but high	Not given	Doused with ammonia liquor from a 130 ft tower	2 M	One victim experienced dyspnea, coughing up frothy pink mucus, severe burns of the face and mouth, red, congested and edematous fauces, no bronchospasm, and normal chest radiograph. Mixed lung functions 5 y later. The second victim, possibly exposed longer, experienced pain in throat and eyes, pink frothy sputum and burns of the face and mouth, with clear chest radiograph. Progressive improvement in ventilation, but consistent depression of the transfer factor. Both victims continued to smoke.	Walton (1973) B-11
NH_3, unknown, but high	Not given	Compressor pump burst under pressure, releasing an ammonia cloud.	2 M	One man died in the accident. The other victim suffered tightness of chest, blepharospasm, blood-stained sputum, and loss of voice. Gradual improvement to normal ventilation values and low normal transfer factor after 5 y.	Walton (1973) B-11
NH_3, unknown, but high	Not given	Metal fragment pierced a pipe of an ammonia condenser in an occupied bomb-shelter.	47	9/47: Relatively "mild" exposure. Main features were acute pharyngitis and tracheitis. Improved rapidly. 25/47: "Moderate" exposure. Main features were acute bronchitis, cough with bloodstained sputum, and exaggeration of the symptoms of the mild cases. 3/25 developed and died of pulmonary edema, 3/25 died of bronchopneumonia, 15/25 recovered completely. 11/47: "Severe" exposure. Pulmonary edema, slight cyanosis, intense dyspnea, and cough with frothy sputum. 7/11 had deterioration in their general condition and died. 4/11 recovered.	Caplin (1941) B-10
NH_3, unknown, but high	< 30 min	Car driving into a portion of exploding tank truck carrying anhydrous ammonia.	1 F 2 M	Exposure to both liquid and gaseous ammonia. Two victims had epithelial defects of the cornea bilaterally and full-thickness burns of the face and mucous membranes of the upper airways and particularly the larynx. On follow-up (1 y or 2 mo), there were no significant pulmonary sequelae with regard to activity restriction. Third victim was exposed longer, had additional injuries (burns of the entire airway and overwhelming pulmonary edema), and eventually died.	Close (1980) B-9

(continued)

TABLE V-2. (continued)

Compound(s) and Concentration(s) in mg/m^3	Duration of Exposure	Accident Description(s)	No. of Accident Victims	Description	Reference and Rating
NH_3, unknown, but high	$\geq$ 30 min	Drove into an ammonia cloud from an exploding tank truck.	5	First degree burns of the face, eyes, and exposed skin, and no upper airway obstruction, although some had greater than first degree burns. Then gradual deterioration of pulmonary functions over 2 to 6 mo, followed by slight improvement with no subsequent change over 2 y.	Close (1980) B-9
NH_3, unknown, but "moderate"	5-10 min	In a car in the vicinity of an exploding tank truck containing anhydrous ammonia.	3	Few clinical findings: conjunctival irritation. Essentially no long-term pulmonary sequelae.	Close (1980) B-9
NH_3, unknown, but high	$\leq$ 30 min	Train derailment causing a cloud of anhydrous ammonia fumes.	2 F	One victim suffered convulsions, burns of skin, soft palate and oropharynx, corneal damage, and respiratory distress. One year later, had bilateral pneumonia and acute right heart failure. Two years later, had hypoxemia, decreased vital capacity, and respiratory pathology. Second victim had burns of the soft palate and oropharynx. Two years later, continued cough, shortness of breath, greenish sputum, and lung function studies indicative of obstruction of the small airways.	Kass et al. (1972) B-9
NH_3, unknown, but high	< 1 min	Spray from a safety relief valve on an anhydrous ammonia nurse tank.	1 M	Facial burns, pulmonary edema, pneumonitis, and inflammation and edema of the upper airways. No residual lung damage occurred.	Helmers et al. (1971) B-8
NH_3, unknown	~ 1 min	Ruptured refrigerator tubing	1 F	Immediate dyspnea and burning eyes. Hospitalized 20 d later in respiratory distress. Condition degenerated, suggestive of subacute bronchiolo-alveolitis, complicated by pneumomediastinum followed by coma. One year later, still had clinical symptoms of chronic bronchitis, radiological signs of bronchiectasis, and lung functions indicative of obstructive syndrome.	Sestier et al. (1969) B-8
NH_3, unknown	< 1 h	Explosion in an ice cream factory due to the bursting of a pipe conveying ammonia gas.	6 F	All suffered from shock and skin burns. Some had conjunctivitis, tracheitis, and bloodstained vomitus probably due to the pharynx. Several developed bronchitis, or aggravated existing bronchitis. 3/6 had some "nervous" symptoms: minor delirium, migraine headaches, continued anxiety, or insomnia. One victim died, with acute laryngotracheitis, tracheobronchitis and bronchopneumonia, and evidence of toxemia from the burns manifested by nephritis.	Slot (1938) B-7

(continued)

TABLE V-2. (concluded)

Compound(s) and Concentration(s) in mg/m^3	Duration of Exposure	Accident Description(s)	No. of Accident Victims	Description	Reference and Rating
NH_3, unknown	Not given	Explosion of a tank containing NH_3 gas, in a soda factory.	4 M	All suffered from burning eyes and pharynx, dyspnea, cough, and some degree of difficulty in swallowing. Some had dizziness, violent headaches, nausea, or inflammation of the digestive tract. One developed pulmonary edema. 3/4 still had slight respiratory insufficiency (possibly due to obesity or smoking and drinking habits), otherwise no sequelae.	Pernot et al. (1972) B-6

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D--.** In 1946, the M.A.C. for NH_3 was 100 ppm.

3-208 ACGIH, American Conference of Governmental Industrial Hygenists TLV Airborne Contaminants Committee. 1981. TLVs Threshold Limit Values for Chemical Substances and Physical Agents in the Workroom Environment with Intended Changes for 1981. ACGIH. Cincinnati, Ohio.

D--. The TLV time-weighted-average for NH_3 is 25 ppm (18 mg/m^3) and the short-term-exposure-limit TLV is 35 ppm (27 mg/m^3).

3-220 AIHA, American Industrial Hygiene Association. 1978. Hygienic Guide Series; Anhydrous Ammonia. American Industrial Hygiene Association. Akron, Ohio. 5 pp.

D--. Brief review.

3-176 Anderson, D. P., C. W. Beard, and R. P. Hanson. 1964. The Adverse Effects of Ammonia on Chickens Including Resistance to Infection with Newcastle Disease Virus. Avian Dis. 8:369-379.

B-12. Four species were exposed to different levels of ammonia for varying lengths of time, up to 6 wk. Pathological changes were seen, varying with time, NH_3 level, and species. Little significant pathology was seen in animals exposed to 20 ppm NH_3 or less for periods of less than 6 wk. Prior exposure to NH_3 increased the number of chickens infected when challenged with Newcastle disease virus.

3-175 Anderson, D. P., C. W. Beard, and R. P. Hanson. 1966. Influence of Poultry House Dust, Ammonia and Carbon Dioxide on the Resistance of Chickens to Newcastle Disease Virus. Avian Dis. 10:177-188.

C-11. Groups of 20 chickens were exposed to dust alone, a combination of dust, NH_3 (30 ppm) and CO_2 (5,000 ppm), or a combination of the gases alone for different time intervals, from 6 h to 8 d. Exposures including NH_3 caused some loss of cilia in the upper trachea

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* MRI document acquisition numbers are given in the left margins.

** MRI rating system is described on pages 11-13.

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and the turbinates. Subsequent exposure to Newcastle disease virus, and no further air pollutant exposure, had no effect on mean death time or percent mortality.

3-177 Anderson, D. P., R. R. Wolfe, F. L. Cherms, and W. E. Roper. 1968. Influence of Dust and Ammonia on the Development of Air Sac Lesions in Turkeys. Am. J. Vet. Res. 29:1049-1058.

B-13. About the best of the poultry/farm studies reviewed. Turkeys exposed to combinations of low or high dust and NH_3 for 2-10 wk were not significantly affected with regard to mortality and feed conversion. High concentrations of both components increased the incidence of air sac lesions and respiratory histopathological changes. No experiments were done with NH_3 alone.

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D-2. Albino rats exposed to a mixture of chloroprene (0.89 mg/m^3), dodecylmercaptan (0.12 mg/m^3), and NH_3 (2.07 mg/m^3) for 1-120 days had increased frequency of chromosomal rearrangements compared to controls, with a maximum at the end of the exposure period. Eleven shoe factory workers occupationally exposed to a mixture of these compounds (4-10 mg NH_3/m^3) had a statistically significant increase in the frequency of chromosomal aberrations in the lymphocytes of the peripheral blood.

3-178 Banister, J., G. Fegler, and C. Hebb. 1949. Initial Respiratory Responses to the Intratracheal Inhalation of Phosgene or Ammonia. Quart. J. Exp. Physiol. 35:233-250.

C-10. Sixteen intact dogs and 13 intact cats were exposed to NH_3 (1/1,000 to 1/250, vol./vol.) for less than 1 min, resulting in accelerated, shallower breathing. Other respiratory details varied with species. Tests were also done on rabbits, vagotomized and sympathectomized cats and dogs, and isolated dog lungs.

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C-10. Negligible data given for the single chemicals, considered as "standard irritants." For each NH_3 concentration four mice were exposed for 30 min, decreases in respiratory rates monitored, and a dose-response curve constructed. From this curve, the RD_{50} (50% decrease in respiratory rate) for ammonia was 303 ppm.

3-111 Battista Raffi, G., D. Cascella, F. Morisi, and R. Caudarella. 1979. Correlazione tra Inquinamento Gassoso Ambientale e Precocità di Comparsa della Pneumoconiosi nei Fonditori di Ghisa [Correlation Between Atmospheric Gaseous Pollutants and the Appearance of Pneumoconiosis in Cast Iron Foundries]. Ingegneria. No. 9-10:270-272.

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3-010 Bhown, A. S., B. B. Maitrya, and M. Bhown. 1971. Ammonia Retention by Smokers: A Comparative Study. Indian J. Med. Res. 59:1296-1299.

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D-8. An epidemiological study of a chemical factory with 30,000 employees exposed to asbestos found the most frequent occurrence of malignant neoplasms in those operations also involving NH_3. Workroom air exceeded the M.A.C. of 25 mg NH_3/m^3 by 2-3 times. No data on specific chemicals or industrial sections given. Probably confounding due to other compounds and smoking.

3-011 Bittersohl, G. 1971b. Epidemiologic Study on Cancer of Workers in a Chemical Plant. Presented at the XVI International Congress on Occupational Health, Tokyo, 1969. Toyko, Japanese Industrial Safety Association. pp. 250-252.

C-6. Apparently the same study as Bittersohl (1971a) [3-012]. A better rating was given because of the clearer distinctions between the NH_3 group and others. No asbestos exposure discussed. Workers in ammonia production plants (50-75 mg/m^3) had higher rates of cancer (lung, stomach, lymphatic tissue, urinary tract) than other workers in the chemical industry. Both groups of workers exceeded cancer rates for the general population of the GDR (especially respiratory and digestive systems in men, and breast, genitals, and lymphatic system for women). Possible exposure to other factors wasn't mentioned and apparently age-adjusted rates were not used.

3-015 Boyd, E. M., M. L. MacLachlan, and W. F. Perry. 1944. Experimental Ammonia Gas Poisoning in Rabbits and Cats. J. Ind. Hyg. Toxicol. 26:29-34.

C-8. Two to seven cats and 11-17 rabbits were exposed to 7,000 mg NH_3/m^3 (a very high level, in the LD_{50} range) for 1 h, then followed immediately or in the second day by analysis of the respiratory tract. There were increases in: output of tracheal tract fluid, iron content (especially tracheal), blood hemoglobin 24 h after gassing, and plasma lipids involving the cholesterol fraction. Respiratory tract water and chloride content and serum chloride content were unaffected.

3-182 Broderson, J. R., J. R. Lindsey, and J. E. Crawford. 1976. Role of Environmental Ammonia in Respiratory Mycoplasmosis of Rats. Am. J. Path. 85(1):115-130.

B-12. Doses used were rather high (150-250 ppm), but the study was well done. The "controls" were exposed to ~ 10 ppm, apparently considered a no-effect dose by the authors.

3-018 Caplin, M. 1941. Ammonia-Gas Poisoning. Forty-seven Cases in a London Shelter. Lancet. 2:95-96.

B-10. Gaseous ammonia was released in an occupied bomb shelter when a flying metal fragment pierced a pipe of an ammonia condenser. No quantitative exposure data. Paper does a good job of describing symptoms. Note the reversibility of the mild cases. Deaths following moderate exposures were due to bronchopneumonia; antibiotics would have helped.

3-221 Caveny, D. D., C. L. Quarles, and G. A. Greathouse. 1981. Atmospheric Ammonia and Broiler Cockerel Performance. Poult. Sci. 60(3):513-516.

C-13. Exposure of chickens to 25 and/or 50 ppm NH_3 for 28 or 49 d had no effect on avg. body wts., number of air sac lesions, or paired-lung and bursa of Fabricius wts. Feed efficiencies were inversely related to ambient air levels of NH_3 and the length of exposure.

3-179 Charles, D. R., and C. G. Payne. 1966a. The Influence of Graded Levels of Atmospheric Ammonia on Chickens. I. Effects on Respiration and on the Performance of Broilers and Replacement Growing Stock. Br. Poul. Sci. 7:177-187.

B-12. Chickens exposed to 50-100 ppm NH_3 for 19-56 days showed decreased food consumption, and decreased growth rate and respiration rate at the higher NH_3 concentration.

3-180 Charles, D. R., and C. G. Payne. 1966b. The Influence of Graded Levels of Atmospheric Ammonia on Chickens. II. Effects on the Performance of Laying Hens. Br. Poul. Sci. 7:189-198.

C-11. Groups of 27 or 36 chickens were exposed to 50 or 100 ppm NH_3 for 10 or 22 weeks. At the higher concentration, egg production, food intake, and live-weight gain were decreased, with no recovery of production after exposure stopped. Trials run at high temperatures had more severe effects. A supplemented diet was able to overcome the deleterious effects of NH_3 on egg production.

3-113 Close, L. G., F. I. Catlin, and A. M. Cohn. 1980. Acute and Chronic Effects of Ammonia Burns on the Respiratory Tract. Arch. Otolaryngol. 106(3):151-158.

B-9. Twelve survivors of an accidental NH_3 spill fell into two groups (short exposure to high concentrations, and longer exposure to lower concentrations), each with different medical problems.

3-114 Cole, T. J., J. E. Cotes, G. R. Johnson, H. DeV. Martin, J. W. Reed, and M. J. Saunders. 1977. Ventilation, Cardiac Frequency and Pattern of Breathing During Exercise in Men Exposed to O-Chlorobenzylidene Malononitrile (CS) and Ammonia Gas in Low Concentrations. Q. J. Exp. Physiol. Cogn. Med. Sci. 62(4):341-352.

B-11. Ammonia was used as a "standard irritant" in an experiment exposing 12 or 18 men to fairly high levels, 71-235 mg/m^3, for about 20 min. During submaximal exercise, ventilation minute volume was reduced about 6% by apparently different mechanisms at low and high doses. No effect was seen on cardiac frequency.

3-020 Cook, W. A. 1945. Maximum Allowable Concentrations of Industrial Atmospheric Contaminants. Ind. Med. 14:936-946.

D--. List of M.A.C.'s for 1945. That for NH_3 was 100 ppm.

3-021 Coon, R. A., R. A. Jones, L. J. Jenkins, Jr., and J. Siegel. 1970. Animal Inhalation Studies on Ammonia, Ethylene Glycol, Formaldehyde, Dimethylamine, and Ethanol. Toxicol. Appl. Pharmacol. 16:646-655.

B-12. Five species were repeatedly or chronically exposed to 40-770 mg NH_3/m^3, with varied effects.

3-022 Couturier, Y., M. Barbotin, P. Bobin, and J.-P. Derrien. 1971. A propos de trois cas de poumon toxique par vapeurs d'ammoniaque et d'hydrogene sulfuré [Three Cases of Toxic Lung from Ammonia and Hydrogen Sulfide Vapors]. Bull. Soc. Med. Afr. Noire Lang. Fr. 16:250-252.

C-5. Short-term exposure to wastewater, both the liquid and the toxic gas mixture, caused the rapid death of one sailor, and cardiac and respiratory problems with eventual recovery in two other sailors.

3-023 Cralley, L. V. 1942. The Effect of Irritant Gases Upon the Rate of Ciliary Activity. J. Ind. Hyg. Toxicol. 24:193-198.

D-6. Exposure to 600 ppm NH_3 for 10 min caused the cessation of ciliary activity without recovery in excised rabbit tracheal tissue.

3-024 Curtis, S. E. 1972. Air Environment and Animal Performance. J. Anim. Sci. 35:628-634.

D--. A review of the literature and a discussion of the problem of studying the effects of all types of airborne pollutants on livestock.

3-025 Curtis, S. E., C. R. Anderson, J. Simon, A. H. Jensen, D. L. Day, and K. W. Kelley. 1975. Effects of Aerial Ammonia, Hydrogen Sulfide and Swine-House Dust on Rate of Gain and Respiratory-Tract Structure in Swine. J. Anim. Sci. 41:735-739.

B-12. Pigs were exposed to NH_3 at 50 or 75 ppm, alone or with dust or hydrogen sulfide. Useful interaction study.

3-027 Dalhamn, T. 1956. Mucous Flow and Ciliary Activity in the Trachea of Healthy Rats and Rats Exposed to Respiratory Irritant Gases (SO_2, H_3N, HCHO). VIII. The Reaction of the Tracheal Ciliary Activity to Single Exposure to Respiratory Irritant Gases and Studies of the pH. Acta Physiol. Scand. 36(Suppl. 123):93-105.

C-6. Groups of two or three rats were exposed to 3, 6.5, 10, 20, 45, or 90 ppm NH_3 until ciliary activity stopped. This occurred at 8 min and 5 sec for the lowest and highest concentrations, respectively, with recovery of ciliary movement within 30 s after exposure stopped.

3-026 Dalhamn, T. 1963. Effect of Ammonia Alone and Combined with Carbon Particles on Ciliary Activity in the Rabbit In Vivo, with Studies of the Absorption Capacity of the Nasal Cavity. Air Water Pollut. 7:531-539.

D-7. Groups of 10 extirpated rabbit tracheas were exposed to high levels of NH_3 (75-2,000 ppm) for 45 min, alone or with carbon particles. 100 ppm was the threshold NH_3 level to cause slowing of ciliary beating, and there was only a slight possible synergism between NH_3 and carbon particles. There was considerable NH_3 absorption in the nasal cavity.

3-028 Dalhamn, T., and L. Reid. 1967. Ciliary Activity and Histologic Observations in the Trachea After Exposure to Ammonia and Carbon Particles. In: Inhaled Particles and Vapors II. Proceedings of an International Symposium. 1965. C. N. Davies, ed. Pergamon Press. New York, New York. pp. 299-306.

C-7. Two groups of 10 rats were exposed to 100 ppm NH_3, alone or in combination with 7.0 mg carbon/m^3 in repeated doses for 60 days.

On day 60 only the group exposed to both NH_3 and carbon showed a decreased rate of tracheal ciliary beating, and all groups had increased mucosal damage although the combination group had the most severe damage.

3-029 Dalhamn, T., and J. Sjöholm. 1963. Studies of SO_2, NO_2, and NH_3: Effect on Ciliary Activity in the Rabbit Trachea of Single *In Vitro* Exposure and Resorption in Rabbit Nasal Cavity. Acta Physiol. Scand. 58:287-291.

D-6. Single excised rabbit tracheas were exposed to a concentration of NH_3 in the range of 200-1,000 mg/L for 20 min. For 5 min exposure, 500-1,000 mg/L NH_3 was needed to cause cessation of ciliary activity. There was 93-96% resorption of 2,000 mg/L NH_3 in the rabbit nasal cavity.

3-116 Dautov, F. F. 1977. K Gigienicheskoi Kharakteristike Uslovii Truda v Proizvodstve Organicheskikh Perekisei [Hygienic Characteristics of the Working Conditions in the Production of Organic Peroxides]. Kazan. Med. Zh. 58(3):89-91.

D-5. Work atmosphere polluted by many compounds, including NH_3 (1-15 mg/m^3). Workers suffered from grippe, angina, acute respiratory disease, and pneumonia.

3-117 Dautov, F. F. 1978. Gigienicheskaya Otsenka Zagryazneniya Vozdukha Benz(a)pirenom i Toksicheskimi Veshchestvami v Proizvodstvakh Polietilena Vysokogo Davleniya i Organicheskikh Perekisei [Hygienic Evaluation of Air Pollution by Benz[a]pyrene and Toxic Substances in the Production of High Pressure Polyethylene and Organic Peroxides]. Gig. Tr. Prof. Zabol. No. 2:1-4.

D--. NH_3 was one of numerous compounds found in the air during the title processes at or below the maximum allowable concentration. No health effects information is given in this article. Hygienic measures are described for lowering the benzpyrene concentrations.

3-183 Diesch, S. 1974. Potential Occupational Health Hazards of Livestock Producers Working in Animal Confinement Units. In: Proceedings of the Society for Occupational and Environmental Health: Conference on Agricultural Health and Safety, University of Iowa, Iowa City, Iowa. Sept. 4-5, 1974. Society for Occupational and Environmental Health. New York, New York. 141-152.

D--. Review of the possible hazards due to toxic gases, and the survival of pathogens in animal manure.

3-118 Dodd, K. T., and D. R. Gross. 1980. Ammonia Inhalation Toxicity in Cats: A Study of Acute and Chronic Respiratory Dysfunction. Arch. Environ. Health. 35(1):6-14.

B-11. A group of 20 cats was exposed to 1,000 ppm NH_3 for 10 min. There was good correlation between the pulmonary function tests (7) and lung histological samples taken at intervals up to 35 days after exposure. The acute effects of the initial insult were followed by indications of chronic respiratory dysfunction. Good pathophysiology for high doses.

3-030 Doig, P. A., and R. A. Willoughby. 1971. Response of Swine to Atmospheric Ammonia and Organic Dust. J. Am. Vet. Med. Assoc. 159:1353-1361.

B-11. Pigs were exposed at the fairly high level of 100 ppm for 1-6 weeks, alone and in combination with dust. Histopathologic changes were seen in the nasal and tracheal epithelium after 2 weeks. Swine a very useful analog for human skin and digestive system and adequate for the respiratory system. A nice study, with the fairly high levels (~ 100 ppm) and few numbers being the only limits.

3-031 Doll, R., M. P. Vessey, R. W. R. Beasley, A. R. Buckley, E. C. Fear, R. E. W. Fisher, E. J. Gammon, W. Gunn, G. O. Hughes, K. Lee, and B. Norman-Smith. 1973. Mortality of Gasworkers--Final Report of a Prospective Study. Br. J. Ind. Med. 29:394-406.

D-11. Excess mortality from bronchitis was found in workers exposed to NH_3, benzene, S, tar, etc., in "retort house." Too complicated a mixture for the purposes of this task.

3-119 Donham, K. J., M. Rubino, T. D. Thedell, and J. Kammermeyer. 1977. Potential Health Hazards to Agricultural Workers in Swine Confinement Buildings. J. Occup. Med. 19(6):383-387.

C-6. NH_3 was one of four gases measured in 13 swine confinement buildings, exceeding the TLV in two units in the summer, and meeting or exceeding the TLV in 12 units in the winter. The 11 full-time and 10 part-time employees and 35 veterinarians surveyed complained of adverse respiratory symptoms, and a physical examination of two workers did not reveal the pathogenesis of their symptoms.

3-120 Drummond, J. G., S. E. Curtis, and J. Simon. 1978. Effects of Atmospheric Ammonia on Pulmonary Bacterial Clearance in the Young Pig. Am. J. Vet. Res. 39(2):211-212.

B-10. Young pigs were exposed to an aerosol of nonpathogenic E. coli, then retained for a 2-h clearance period in 50 or 75 ppm NH_3. Viable bacteria counts in the lungs were greater in the ammonia-exposed groups than in the controls.

3-033 El-Sewefy, A. Z., and S. Awad. 1971. Chronic Bronchitis in an Egyptian Ice Factory. J. Egypt. Med. Assoc. 54:304-310.

C-6. The paper reports on a poorly designed epidemiological study. There were no quantitative exposure data.

3-207 Ernst, R. A. 1968. The Effect of Ammonia on Poultry. Feedstuffs. 40(32):40.

D--. A very short review, with no references.

3-174 Fairhall, L. T. 1949. Industrial Toxicology. Williams and Wilkins. Baltimore, Maryland. pp. 13-14.

D--. A short review of the properties, sources and uses, toxicity, and analysis of NH_3.

3-122 Ferguson, W. S., W. C. Koch, L. B. Webster, and J. R. Gould. 1977. Human Physiological Response and Adaptation to Ammonia. J. Occup. Med. 19(5):319-326.

A-11. Six unacclimated volunteers were exposed to 25, 50, and 100 ppm NH_3 for 6 h/d over 6 weeks in an industrial environment. After 2-3 weeks acclimation, there was inurement to eye, nose and throat irritation, no impairment of ability to perform job duties, no change in vital functions measured, and toleration of occasional brief exposures to 200 ppm.

3-034 Fieldner, A. C., S. H. Katz, and S. P. Kinney. 1921. Ammonia. In: Gas Masks for Gases Met in Fighting Fires. Bureau of Mines Technical Paper 248. U.S. Government Printing Office, Washington, D.C. pp. 13-14.

D--. A very short review of the hazards of NH_3, and minor first aid after exposure, for firemen. Not relevant to this study.

3-186 Flury, F., and F. Zernik. 1931. Ammoniak [Ammonia]. In: Schädliche Gase. Dämpfe, Nebel, Rauch-und Staubarten [Noxious Gases--Vapors, Mist, Smoke, and Dust Particles]. Julius Springer, Berlin, Germany. pp. 150-154.

B--. Review of acute and chronic animal and human NH_3 exposure.

3-036 Gadaskina, I. D. 1972. Ammonia (NH_3), Ammonium ($(NH_4)^+$). In: Encyclopedia of Occupational Health and Safety, Vol. 1. International Labour Office, McGraw-Hill. New York, New York. pp. 97-98.

D--. Short review of occurrence, production, uses, hazards, and safety measures.

3-123 Gallagher, J. T., R. L. Hall, P. K. Jeffery, R. J. Phipps, and P. S. Richardson. 1978. The Nature and Origin of Tracheal Secretions Released in Response to Pilocarpine and Ammonia. J. Physiol. (London). 275:36P-37P.

D-7. Scant methodology given, referring to other papers. Short exposure to 2,000 ppm NH_3 increased the output of ^{3}H-labeled mucus, and caused the discharge of mucus from glands, goblet cells, and the release of a distinct glycoprotein from the surface of ciliated cells.

3-181 Gaspar, E., P. H. Sammelwitz, C. R. Richards, and M. S. Cover. 1961. The Influence of Atmospheric Ammonia on Blood Hemoglobin Levels. Am. Soc. Anim. Science N. Atlantic Section Proc. 3:68-74.

C-9. Exposure of chickens to 7.4, 23, or 45 ppm NH_3 for 12 wk caused changes in rate of hemoglobin formation only at the highest concentration. That level also caused keratoconjunctivitis and blindness.

3-037 Gaume, J. G., P. Bartek, and J. H. Rostami. 1971. Experimental Results of Time of Useful Function (TUF) After Exposure to Mixtures of Serious Contaminants. Aerosp. Med. 42:987-990.

C-8. Mice were exposed to gas mixtures and timed until collapse on an exercise wheel, which occurred within minutes. Useful interaction study, but high concentrations (0.25-1.5% NH_3) were tested and no straight NH_3 testing was done.

3-038 Giguz, T. L. 1968. Effect of Low Concentrations of Ammonia and Nitrogen Oxides on Adolescents Undergoing Vocational Training in the Chemical Industry. Hyg. Sanit. 33(7-9):431-434.

B-6. Occupational exposure of adolescents to both ammonia and nitrogen oxides at concentrations lower than the maximum allowable (e.g., 20 mg NH_3/m^3) caused definite changes in fat metabolism and protein metabolism and caused a higher incidence of upper respiratory tract diseases. Any effects due to NH_3 are confounded by the presence of NO_x.

3-040 Golyakova, L. P. 1971. Present-day State of Industrial Hygiene Problems in Hydrometallurgical Production of Tungsten and Molybdenum Salts and Oxides. PB 254580T, National Technical Information Service, U.S. Department of Commerce, Springfield, Virginia. 10 pp.

D-6. Dust, NH_3, H_2S, and HCl were encountered. The most frequent NH_3 concentration in working areas was in the range of tens and hundreds of milligrams per cubic meter. No real exposure data, little toxicity data.

3-041 Haggard, H. W. 1924. Action of Irritant Gases Upon the Respiratory Tract. J. Ind. Hyg. 5:390-398.

D--. A description of mechanisms. Obsolete.

3-128 Hatton, D. V., C. S. Leach, A. L. Beaudet, R. O. Dillman, and N. Di Ferrante. 1979. Collagen Breakdown and Ammonia Inhalation. Arch. Environ. Health. 34(2):83-87.

C-10. Three young boys and one female (17-y-old), accidentally exposed to concentrated ammonia vapors, had increased urinary metabolites of hydroxylysine, compared to two other normal children.

This indicates considerable collagen degradation, perhaps related to the pulmonary and upper respiratory lesions and inflammation observed on clinical examination.

3-042 Heifer, U. 1970. Kasuistischer Beitrag zur akuten, letalen, inhalatorischen Ammoniakvergiftung [Casuistical Report on an Acute, Lethal, Inhalation Poisoning by Ammonia]. Lebensversicherungsmedizin. 22:60-62.

C-8. A 30-year-old office worker was accidentally exposed to a high concentration of NH_3 fumes after losing consciousness following a thrombosis. Death was due to the ensuing glottal, epiglottal, and hemorrhagic lung edema. There was also toxic hemorrhagic liver cell necrosis.

3-043 Helmers, S., F. H. Top, Sr., and L. W. Knapp, Jr. 1971. Ammonia Injuries in Agriculture. J. Iowa Med. Soc. 61:271-280.

B-8. Case reports of exposures to very high NH_3levels.

3-044 Henderson, Y., and H. W. Haggard. 1943. Noxious Gases and the Principles of Respiration Influencing Their Action. 2nd ed. Reinhold Publishing Corporation, New York, New York. pp. 125-126.

D--. A short review of properties, sources, and health effects.

3-129 Herrman, G., and J. Viehrig. 1979. Irritative Atemwegserkrankungen durch Ammoniak und Schwefelsäureaerosole in einer Kuoxamseidespinnerei [Irritative Respiratory Tract Diseases from Ammonia and Sulfuric Acid Aerosols in a Cuprammonium Rayon Spinning Mill]. Z. Gesamte Hyg. 25(8):581-584.

A-9. Lung functions of the exposed workers were impaired compared to control group of workers. Some consideration of possible compounding factors, such as sex and smoking habits.

3-130 Hilado, C. J., H. J. Cumming, A. M. Machado, C. J. Casey, and A. Furst. 1978. Effect of Individual Gaseous Toxicants on Mice. Proc. West. Pharmacol. Soc. 21:159-160.

D-8. Groups of four male mice were used to determine a 30-min LC_{50} for NH_3 of 21,430 ppm.

3-131 Hollett, B. A. 1977. Health Hazard Evaluation/Toxicity Determination Report 76-91-371, Safeway Stores, Inc. Distribution Center, Landover, Maryland. PB-270859, National Technical Information Service, U.S. Department of Commerce, Springfield, Virginia. 12 pp.

C-7. Evidence that humans can stand intermittent, moderate exposure to NH_3 with no obvious aftereffects. NH_3 concentrations from air samples taken considered invalid, so precise level of exposure unknown.

3-045 Horvath, A. A. 1924/1925. The Action of Ammonia Upon the Lungs. Proc. Soc. Exp. Biol. Med. 22:199-200.

D-6. A much less detailed report of the same experiment described in Horvath (1926) [3-046].

3-046 Horvath, A. A. 1926. The Action of Ammonia Upon the Lungs (Part I). Jap. Med. World. 6:17-29.

C-7. A single rabbit or guinea pig was exposed to an ammonia concentration in the range of 1,200-15,200 ppm for 4-53 days. There were no macroscopic changes in the respiratory organs of guinea pigs exposed to the lower level, both species died at the higher concentration, and there were pathological findings in both species exposed to the intermediate concentrations.

1-0172 ILO. 1970. Permissible Levels of Toxic Substances in the Working Environment. Occupational Safety and Health Series 20, International Labour Office, Geneva, Switzerland. pp. 194-198.

C--. Maximum Acceptable Concentrations in Czechoslovakia.

	Normal MAC (mg/m^3)	Short, Single Exposure MAC (mg/m^3)
Acrolein	0.5	1.0
NH_3	40	80
HCHO	2	5
HCN	3	15
MeOH	100	500
H_2S	30	-

3-104 ILO/WHO, International Labour Office/World Health Organization. 1969. Permissible Levels of Occupational Exposure to Airborne Toxic Substances. Sixth Report of the Joint ILO/WHO Committee. WHO Technical Report Series No. 415, World Health Organization, Geneva, Switzerland. 16 pp.

D--. Discussion of the general principles and problems in recommending international limits on occupational exposure. The recommended "safe concentration zone" for NH_3 was 20-35 mg/m^3.

3-047 ILO/WHO, International Labour Office/World Health Organization. 1970. Permissible Levels of Toxic Substances in the Working Environment. In: Sixth Session of the Joint ILO/WHO Committee on Occupational Health. June 4-10, 1968. International Labour Office. Geneva, Switzerland. pp. 13, 194, 199, 212, 217, 222, 229, 242, 244, 253, 263-264, 267-268, 276, 290, 329-330, 345.

D--. A compilation of various national M.A.C.'s for the working environment, those for NH_3 ranging from 20 to 70 mg/m^3. Variations between states in the United States included.

3-132 Ivanov, N. G. 1978. Metodicheskie Podkhody k Opredeleniyu Poroga Razdrazhayushchego Deistviya Promyshlennykh Yadov [Methodological Approaches to Determining the Threshold of the Irritating Action of Industrial Poisons]. Gig. Tr. Prof. Zabol. No. 2:26-30.

C-7. The threshold of irritating action for 4-h NH_3 exposure of white rats was 215 ± 8.4 mg/m^3. Several indexes were used, including respiratory frequency, acuity of sense of smell, and intensified cell migration to the surface of the mucosa of the upper respiratory tract and lungs.

3-133 Jedrychowski, W., K. Prochowska, J. Garlinska, and J. Bruzgielewicz. 1979. Wystepowanie Przewłektych Nieswostych Chorób Układu Oddechowego Wśród Pracownikiv Zakładu Zywic Winylowych [Occurrence of Chronic Nonspecific Diseases of the Respiratory Tract in Workers of a Vinyl Resin Plant]. Przegl. Lek. 36(9):679-682.

D-7. Workers were examined, from different departments with different atmospheres. One group may have been more exposed to NH_3 (0.42-13.39 mg/m^3), along with other compounds, and had significantly higher incidence of chronic bronchitis and lower FEV_1 values.

3-212 Kachnyi, G. G., and V. G. Vinogradov. 1980. Sostoyanie Slizistoi Obolochki Verkhnikh Dykhatel'nyk'n Putei u Tkachikh i Rabochikh Karasil'no-Karbonizatsionnogo Tsekha [State of Upper Respiratory Tract Mucosa in Weavers and Workers in the Textile Dyeing and Carbonizing Departments]. Zh. Ushn., Nos. Gorl. Bolezn. No. 3:35-38.

D--. Workers who dyed and cleaned wool by carbonization were exposed to vapors of 3.0-5.0 mg CH_3CO_2H/m^3, 0.5-1.0 mg H_2SO_4/m^3, 10-20 mg NH_3/m^3, 2-6.0 mg dust/m^3, and 0.06-0.08% CO_2.

3-134 Kane, L. E., C. S. Barrow, and Y. Alarie. 1979. A Short-Term Test to Predict Acceptable Levels of Exposure to Airborne Sensory Irritants. Am. Ind. Hyg. Assoc. J. 40(3):207-229.

C-6. A discussion of the use of the short-term test described in Barrrow et al. (1978) [3-110] in proposing threshold limit values, short-term exposure limits, etc.

3-052 Kass, I., N. Zamel, C. A. Dobry, and M. Holzer. 1972. Bronchiectasis Following Ammonia Burns of the Respiratory Tract. A Review of Two Cases. Chest. 62:282-285.

B-9. High dose symptoms; actual exposure unknown, but extreme.

3-053 Kazasov, P. L. Balabayeva, G. Petrova, and M. Mikhov. 1971. Prouchvane Zamyrsyavaneto na Atmosferiya Vyzdukh v Raiona na Azotnotoroviya Zavod Krai Stara Zagora i Vliyanieto mu Vyrkhu Zdraveto na Haselenieto [Study of Air Pollution Around the Nitrogen Fertilizer Plant Near Stara Zagora and Its Effects on the Health of the Population]. Khig. Zdraveopa. 14:46-56 (Bul).

D-4. The atmosphere in the region around a nitrogen fertilizer plant was polluted with several measured compounds, including NH_3 (some areas exceeding the M.A.C. in 1968 and 1969). A study of the population indicated several possible changes in the blood and immunobiological states.

3-135 Kent, P. W., and J. G. Widdicombe. 1977. Neurophysiological Control of Glycoprotein Secretion in the Tracheal Epithelium. Biochem. Soc. Trans. 5(2):414-417.

D-7. The trachea of an anaesthetized cat was labeled with ^{3}H and ^{35}S medium, followed by exposure to NH_3 (1:100). The labeled secreted mucus obtained afterwards was released from goblet cells and had a low sulfate and high sialic acid content.

3-048 Keplinger, M. L., K. J. Schadeberg, J. W. Goode, and J. C. Calandra. 1973. Irritation Threshold Evaluation Study with Ammonia. In: Report to International Institute of Ammonia Refrigeration. Industrial Bio-Test Laboratories, Inc. Northbrook, Illinois. 13 pp.

A-12. Subjective evaluation of the respiratory irritation due to acute exposure of human adults to low levels of NH_3 (32-134 ppm).

5-367 Kettner, H. 1978. Indoor Contamination by Chemical Substances and Their Hygienic Significance. In: Org. Verunreinig. Umwelt: Erkennen, Bewerten, Vermidern, K. Aurand, V. Haesselbarth, E. Lahmann, G.Muller, and W. Niemitz, eds. Erich Schmidt Verlag. Berlin, Germany. pp. 448-453 (Ger.).

C--. Maximum allowable indoor air concentrations in the USSR:

Acrolein	0.1 mg/m^3
NH_3	0.2 mg/m^3
HCN	0.002 mg/m^3
HCHO	0.01 mg/m^3
MeOH	0.5 mg/m^3

3-136 Kirkov, V. 1977. Kyrkhu Nevro-Vegetativnata Reaktivnost na Rabotnitsi ot Amonyachnoto Proizvodstvo [Neuroautonomic Response of Workers in the Ammonia Industry]. Suvrem. Med. 28(10):10-13 (Bul).

C-5. Signs of overexcitability in various nerve tracts were seen at the end of the workday in employees of a NH_3 production plant (perhaps 10-50 mg/m^3 in the atmosphere).

3-210 Klavis, G. 1958. Ammoniakvergiftungen und ihre Folgen unter Berücksichtigung neuer Kasuistik [Ammonia Poisoning and its Consequences, with New Case Reports]. Arch. Toxikol. 17:155-158.

C--. Severe poisoning symptoms in workers after acute exposures to NH_3 escaping from a defective safety valve were described. Exposure levels were not measured. Klavis believed that workers can tolerate

$\leq$ 100 mg NH_3/m^3 without chronic irritation (the MAC was 70 mg/m^3). Protective masks should be worn at higher concentrations.

3-137 Kondrashov, V. A. 1978. O Sootnosheniyakh Opasnosti Otravleniya Parami i Gazami Toksicheskikh Veshchestv pri Kozhnom i Ingalyatsionnam Putyakh Vozdeistviya [Relative Hazards of Poisoning with Fumes and Gases of Toxic Substances with Their Dermal and Inhalation Routes of Action]. Gig. Tr. Prof. Zabol. No.2:34-38.

C-8. The 5-min to 1-h LC_{50} for rats by inhalation of NH_3 is 100 mg/ m^3 compared to 1,300-200 mg/m^3 by skin absorption in the same period.

3-054 Kornienko, A. P. 1972. Gigenicheskaya Otsenka Smesi Aerozolya Sernoi Kisloty, Sernistogo Angidrida, Okislov Azota i Ammiaka kak Zagrayaznitelei Atmosfernogo Vozdukha [Hygienic Evaluation of a Mixture of Sulfuric Acid Aerosol, Nitrogen Oxides, and Ammonia as an Atmospheric Pollutant]. Gig. Sanit. 37(4):8-10.

D--. A study primarily aimed at investigating the joint action of a mixture of compounds. The effect obtained was of the summation type. Human odor threshold and EEG and fat resorptive action, defensive reflex action, cholinesterase activity, liver function, blood, and tissue studies were done.

3-138 Krystev, E., M. Kolev, and P. Konstantinov. 1978. Prouchvaniya Vyrkhu Mikroklimata i Smyrtnostta pri Puicheta Broileri [Microclimate and the Mortality Among Turkey Poult Broilers]. Vet. Med. Nauki. 15(1):8-13 (Bul).

C-7. Groups of 23 turkeys exposed for 20-25 days to 14, 26, or 55 mg NH_3/m^3 and apparently no H_2S showed statistically significant increased mortality (8.55, 24.00, 36.90%) with increased NH_3 concentration. Apparently no controls were used.

3-171 Kujawska et al. 1977. Analiza Sprawnosci Wentylacyjnej Płuc Pracowników Narazonych na Dziatonie Gazów i Pyłow Drazniazcych [Analysis of Lung Function in Workers Exposed to Irritating Dusts and Gases]. Med. Pr. 28(5):419-426.

B-10. Men occupationally exposed to NH_3 alone or in combination with dust and NO_x had decreased FEV_1 values. The effect was further enhanced in smokers.

3-055 Kustov, V. V. 1967. Means for Determining the Maximum Allowable Concentration of Toxic Products of Natural Human Metabolism. In: Obshchiye Voprosy Promyshlenoy Toksikologii [General Questions of Industrial Toxicology]. Moscow, U.S.S.R. NASA Technical Translation, TT F-11,358, National Aeronautics and Space Administration, Washington, D.C. pp. 63-65.

C-7. Gives some biochemical indexes that may be useful for estimating exposure.

3-187 Larson, T. V., D. S. Covert, R. Frank, and R. J. Charlson. 1977. Ammonia in the Human Airways: Neutralization of Inspired Acid Sulfate Aerosols. Science. 197:161-163.

B-11. In humans, natural expired NH_3 concentrations ranged from 7 to 520 $\mu g/m^3$, varying with the last airway segment traversed. Possible neutralization of H_2SO_4 aerosols by NH_3.

3-140 Lee, S. T., and Y. J. Lee. 1977. Survey on Status of Working Environment in Some Industries. Koryo Taehakkyo Uikwa Taehak Chapchi. 14(1):161-170 (Kor).

D-7. Only one data point for NH_3 is given: 43 ppm in the air of an ammonia room in the chemical industry. No toxicity data are given.

3-219 Legters, L. 1980. Biological Effects of Short, High-Level Exposure to Gases: Ammonia. AD-A094501, National Technical Information Service, U.S. Department of Commerce, Springfield, Virginia. 87 pp.

A--. Extensive review of the animal and man NH_3 exposure literature (mainly English), primarily in narrative form. Includes an appendix with summaries and critical analyses of the literature.

3-058 Lehmann, K. B. 1886. Experimentelle Studien über den Einfluss technisch und hygienisch wichtiger Gase und Dämpfe auf den Organismus. (Teil I und II--Amoniak und Salzäuregas) [Experimental Studies on the Effect of Technically and Hygienically Important Gases and Vapors on the Organism. (Parts I and II--Ammonia and Hydrogen Chloride Gas)]. Arch. Hyg. 5:1-126.

B-9. Dose-response experiments with cats, rabbits, guinea pigs, and rats.

3-059 Leonardos, G., D. Kendall, and N. Barnard. 1969. Odor Threshold Determinations of 53 Odorant Chemicals. J. Air Pollut. Control Assoc. 19:91-95.

A-11. Definitive paper on the subject.

3-060 Lépine, C., and R. Soucy. 1962. La bronchopneumopathie d'origine toxique. Evolution physiopathologique [Bronchopneumopathy of Toxic Origin: Physiopathological Evolution]. Union Med. Can. 91:7-11; copyrighted English translation provided by the National Institute of Occupational Safety and Health, Rockville, Maryland.

C-7. The victim of an occupational accidental exposure to NH_3 (concentration and duration not given) showed decreased maximum respiratory capacity and vital capacity over a 16-mo period.

3-202 Lillie, R. J. 1970. Air Pollutants Affecting the Performance of Domestic Animals: A Literature Review. Agriculture Handbook No. 380. Animal Science Research Division, Agriculture Research Service, United States Department of Agriculture, Washington, D.C. pp. 14-19.

D--. Primarily a review article with 28 references. One short section comparing poultry and human susceptibility to NH_3, indicating that poultry may have a slightly higher tolerance.

3-189 Lotoshnikova, Yu. V. 1979. K Gigienicheskoi Otsenke Epoksidno-Furfurol'nogo Pokrytiya [Hygienic Assessment of an Epoxy-Furfural Coating]. Khim. Prom-st., Ser.: Toksikol. Sanit. Khim. Plastmass. No. 4:29-30.

D-4. Epoxy-furfural coating, used on concrete for anti-corrosion purposes, emits many substances after its application, especially NH_3 and furfural. At no time did levels exceed the maximum allowable concentrations, and only traces were left after 4 mo. Slight odor was detected (0.0126 mg furfural/m^3, 0.042 mg NH_3/m^3). Significant changes in human dark adaptation were seen.

3-062 MacEwen, J. D., J. Theodore, and E. H. Vernot. 1970. Human Exposure to E.E.L. Concentrations of Monoethylhydrazine. AMRL-TR-70-102 Paper No. 23. Aerospace Medical Research Laboratory, Aerospace Med. Div., Air Force Systems Command, W-P AFB, Ohio. 9 pp.

C-8. Six men tested found 30 and 50 ppm NH_3 to have a moderate or strong odor intensity, and no to moderate nasal and eye irritation. Subjective evaluation only.

3-144 Makshanova, E. I. 1977. Hekotorye Pokazateli Zabolevaemosti i Nespetsificheskoi Reaktivnosti Organizma Robachikh Otdelochnogo Tsekha Kozhevenogo Proizvodstva [Some Morbidity Indexes and Nonspecific Responses of Leather Industry Finishing Department Workers]. Zdravookhr. Beloruss. No.9:85-86.

D-5. The air in the title area is polluted by NH_3, esters, xylene, toluene, and turpentine in concentrations at or somewhat above the maximum permissible limits. The workers suffered from catarrh of the upper respiratory tract, angina, bronchitis, hypertonic disease, neuralgia, neuritis, and radiculitis.

3-172 Marschang, F., and C. Petre. 1971. Der NH_3-Gehalt der Stalluft und sein Einfluss auf die Morbidität und die Tierverluste in Rindmastställen [The NH_3 Content of Stall Air and Its Influences on Morbidity and Animal Losses in Cattle Fattening Houses]. Zentralbl. Vet. Med. B. 18:646-654.

C-8. There was a direct relationship between too high concentration of NH_3 (3-2,000 ppm by volume) in the buildings, and the development of disease and the severity of signs of the disease (mainly respiratory disorders).

3-173 Martin, W., and A. C. Stern. 1974. The World's Air Quality Management Standards, Vol. I. EPA-650/9-75-001-a, U.S. Environmental Protection Agency, Washington, D.C. 15 pp.

D--. In seven other countries, the ambient air quality standards were 0.1-0.5 mg NH_3/m^3, for 24 h.

3-064 Mayan, M. H., and C. P. Merilan. 1972. Effects of Ammonia Inhalation on Respiratory Rate of Rabbits. J. Anim. Sci. 34:448-452.

B-11. Exposure of rabbits to 50 or 100 ppm for 3 h caused increased depth of respiration, increased blood urea nitrogen and CO_2, and no pathological changes in several organs examined.

3-145 Mickiewicz, L. 1978. Effect of Industrial Pollution on the Mucous Membrane of Upper Respiratory Tract. Med. Pr. 29(1):65-68.

D--. A review of upper respiratory tract effects of ammonia as well as of cotton, wood, and rock salt dusts; HCl; H_2SO_4; and F compounds.

3-065 Mikhailov, V. I., Z. I. Pilipyuk, V. S. Georgievsky, B. S. Katkovsky, and A. N. Kalinina. 1969. Vliyanie Malykh Kontsentratsii Ammiaka na Nekotonye Biokhimicheskie i Fiziologicheskie Pokazateli u Cheloveka [The Effect of Low Concentrations of Ammonia on Certain Biochemical and Physiological Indices in Man]. Gig. Tr. Prof. Zabol. 13(10):53-55.

C-8. Experimental acute exposure of men to low levels of NH_3 (3 or 13 mg/m^3) temporarily altered oxygen consumption.

3-146 Mikhailuts, A. P. 1977. Vliyanie Nizkikh Kontsentratsii Ammiaka na Lits, Perenesshikh Ostrye Zabolevaniya Verkhnikh Dykhatel'nykh Putei [The Effect of Low Concentrations of Ammonia on Persons Recovered from Acute Diseases of the Upper Respiratory Tract]. Gig. Sanit. 9:16-19.

B-9. People in the 2 to 4 days after convalescence were more sensitive to the action of low concentrations of NH_3 than practically healthy people. Odor thresholds of other chemicals, pneumotachometry, and cardiointervalography were studied.

3-213 Mikhailuts, A. P. 1980. Vozdeistvie Zagryaznenii Atmosfernogo Vozdukha Territorii Khimicheskogo Predpriyatiya na Rabotayushchikh, Imeyushchikh Khronicheskie Ishemicheskuyu Bolezn' Serdtsa, Bronkhit i Pnevmoniyu [Effect of Air Pollution in the Area of a Chemical Plant on Workers with Chronic Ischemic Heart Disease, Bronchitis, or Pneumonia]. Gig. Tr. Prof. Zabol. No. 7:1-3.

D--. Chemical plant workers afflicted with the title diseases and exposed during 68-72% of their work shift to NH_3, NO_x, SO_2, and H_2SO_4 [presumably as a mixture] at total concentrations of 0.43-0.61 the MAC (MPC) values showed rapid loss of olfactory response to benzene vapors and an increase of heartbeat and breathing rates despite only light to moderate exertion. Changes absent or barely detectable in healthy controls.

3-147 Mikhailuts, A. P., V. A. Poponnikov, I. V. Golubev, and S. A. Lambina. 1979. Vliyanie Ammiaka i Dvuokisi Azota na Razvitie Respiratornykh Mikrobnykh Infektsii [Effect of Ammonia and Nitrogen Dioxide on Respiratory Microbial Infections]. Gig. Sanit. No. 8:8-11.

B-10. Chronic exposure of rats to low concentrations of NH_3 (3 or 6 mg/m^3) and repeated innoculation with respiratory-infection microbes caused increased pathomorphology compared to rats with no gas exposure.

3-206 Mitchell, H. A. 1963. Ammonia Tolerance of the California Leaf-Nosed Bat. J. Mammal. 44(4):543-551.

B-9. Acute exposure of bats to 500-5,500 ppm NH_3 indicates that they are much less sensitive than humans. Organ damage and decreased respiratory and heart rates were seen. The maximum sublethal concentration tolerated for 9 h was 3,000 ppm.

3-148 Montague, T. J., and A. R. Macneil. 1980. Mass Ammonia Inhalation. Chest. 77(4):496-498.

C-10. Fourteen men, accidentally exposed to high concentrations of ammonia vapors for up to several minutes, were differentiated by physical examination into mildly or moderately affected groups. All had significant respiratory distress, some combination of pharyngeal or pleuristic chest pains, cough or dyspnea. Those with abnormal chest findings on admission had longer hospital stays, but both groups responded well to treatment.

3-066 Mulder, J. S., and H. O. van der Zalm. 1967. A Fatal Case of Ammonia Poisoning. Tijdschr. Soc. Geneeskd. 45:458-460; copyrighted English translation provided by the National Institute of Occupational Safety and Health, Rockville, Maryland.

C-8. During an accidental spill, a male worker was exposed to roughly 30,000 ppm NH_3 for several minutes during physical exertion. The first cardiac arrest occurred about 4 h after exposure, and the fatal cardiac arrest 6 h later. On autopsy, destruction of deep lung tissue; pharyngeal, epiglottal, and pulmonary edema; and other respiratory damage were found.

3-067 Nakatani, T., and S. Sugano. 1971. Survey Report Concerning Damages Caused by Air Pollution Due to Waste Gases from Sanitation Center in Yabase. Part I. Effects on the Human Body. Nakadori Byoin Iho [Nakadori Hosp. Bull.]. 11:796-800.

D--. The acute and chronic respiratory complaints of 46 people within 500 m of a sanitation center. It was believed that most of the problems were due to nitrogen compounds but no concentrations were given. No controls.

3-068 NAS/NRC, National Academy of Science/National Research Council Committee on Toxicology. 1972. Guides for Short-Term Exposures of the Public to Air Pollutants. IV. Guide for Ammonia. PB-244336, National Technical Information Service, U.S. Department of Commerce, Springfield, Virginia. 10 pp.

A--. Review of effects on humans, animals, plants, and materials.

3-214 Nefedov, Yu. G., V. P. Savina, N. L. Sokolov, and V. E. Ryzhkova. 1969. Issledovanie Mikroprimesei v Vydykhaemom Chelovekom Vozdukhe [Trace Contaminants in the Air Exhaled by Man]. Kosm. Biol. Med. 3(5):71-77.

D--. Ammonia levels found in the breath of healthy 25 to 35-y-old people were 0.1-1.50 mg/m^3 in smokers and 0.4-1.93 mg/m^3 in nonsmokers.

6-124 Newsome, J. R., V. Norman, and V. L. Zaratzian. 1965. Vapor Phase Analysis of Cigarette Smoke. Tob. Sci. 9:102-110; or Tobacco 161(4):24-32.

D--. Levels in tobacco smoke (µg/40 mL puff):

	Unfiltered	Filtered
Methanol	13	10
HCHO	4.1	3.6
Acrolein	8.2	7.9
HCN	32	29
H_2S	3.4	3.1
NH_3	12	13

3-203 Niden, A. H. 1968. Effects of Ammonia Inhalation on the Terminal Airways. Eleventh Aspen Emphysema Conference. 11:41-44.

D-4. An expanded abstract, so few data are given. Acute exposure of mice to NH_3 (up to 280,000 ppm) caused changes in capillaries, alveoli, and nonciliated bronchiolar cells (examination by electron microscopy).

3-190 NIOSH, National Institute for Occupational Safety and Health. 1979. Working Safely with Anhydrous Ammonia. PB80-184427, U.S. Department of Health, Education, and Welfare, Cincinnati, Ohio. 23 pp.

D--. A general common sense safety booklet. It stresses the toxicity, rapid changes of volume and pressure, and the cooling capacity of ammonia. First aid for NH_3 exposure consists of flushing with water and calling a doctor. Accident avoidance is using the proper equipment in the proper way. Lists causes of most accidents.

3-070 Nizhegorodov, V. M., and I. T. Kalinin. 1967. The Effect of Prolonged Exposure to Low Ammonia Concentrations on the Content of Vitamins A, B_1, B_2, PP and Ascorbic Acid in Animals. Hyg. Sanit. 32(1-3):277-280.

D-6. Exposing rats to 20 mg NH_3/m^3 for 3-7 mo affected metabolism significantly as well as the contents of vitamins B_1, B_2, PP, and ascorbic acid in the animals.

3-071 Nizhegorodov, V. M., and Ya. L. Markhotskii. 1971. Vitamin B_6 Requirement for Workers Occupied in the Manufacture of Nitrogen Fertilizers. Hyg. Sanit. 36(7-9):478-480.

C-7. The vitamin B_6 requirement of workers exposed to NH_3, NO_x, and CO was increased, but only the CO concentration was given in the article.

3-211 NRC, National Research Council, Committee on Medical and Biologic Effects of Environmental Pollutants, Subcommittee on Ammonia. 1979. Ammonia. University Park Press. Baltimore, Maryland. 384 pp.

A--. Authoritative review of properties, chemical interactions, monitoring, sources and sinks, transportation, toxicology, human health effects, and effects on materials.

3-215 OAQPS, Office of Air Quality Planning and Standards. 1977. Air Pollutant Assessment Report on Mobile Source Ammonia Emissions. Strategies and Air Standards Division, Office of Air Quality Planning and Standards, Office of Air and Waste Management, Environmental Protection Agency. Research Triangle Park, North Carolina. 27 pp.

C--. Tailpipe emissions from cars equipped with catalytic converters averaged 3.5 mg NH_3/m^3 when properly adjusted and 14 mg NH_3/m^3 when improperly adjusted. Extensive discussion of a series of tests, and possible NH_3 levels in enclosed areas and in congested traffic. Includes a review of NH_3 health effects literature.

3-074 Patty, F. A. 1963. Alkaline Materials. In: Industrial Hygiene and Toxicology. Vol. 2. Toxicology. 2nd ed. D. W. Fassett and D. D. Irish, eds. Interscience Publishers, New York, New York. pp. 859-869.

D--. Short review of properties, uses, and toxicity of NH_3 and other compounds. Considers mostly relatively high concentrations.

3-075 Pernot, C., C. Huriet, A. Midon, and G. Grun. 1972. L'intoxication aiquë professionnelle par le gaz ammoniac. À propos de quarte observations. [Acute Occupational Poisoning by Ammonia Gas. A Study of Four Cases] Arch. Mal. Prof. Med. Trav. Secur. Soc. 33:5-12.

B-6. Accidental exposure of four men following the explosion of a tank containing NH_3 gas. Some acute symptoms, and apparent recovery with few or no sequelae.

3-204 Phipps, R. J., and P. S. Richardson. 1976. The Effects of Irritation at Various Levels of the Airway Upon Tracheal Mucus Secretion in the Cat. Am. J. Physiol. 261:563-581.

D-6. A mechanism study. NH_3 exposure caused coughing followed by slow, deep breathing. Inhalation into the lower airways caused increased mucus output from the isolated trachea.

3-107 Pliskovskaya, G. N., A. L. Germanova, N. G. Ivanov, E. A. Il'in, V. M. Milyavskii and A. D. Noskin. 1975. Opredelenie Soderzhaniya v Atmosfere Maketov Biosputnikov Ammiaka i Podkhod k ego Normirovaniyu [Determination of the Ammonia Content in the Atmosphere of Biosatellite Mockups and a Method for Its Normalization]. Kosm. Biol. Aviakosmicheskaya Med. 9(2):27-32.

C-6. Tests with 60 rats exposed to NH_3 concentrations for 4 h determined the threshold of irritating action to be 228 mg/m^3, the threshold of acute action to be 462 mg/m^3, and the no-effect level to be 115 mg/m^3. Rats held for 30 days in conditions of hypokinesia before testing had threshold values roughly half those for normal rats.

3-151 Quarles, C. L., and D. J. Fagerberg. 1979. Evaluation of Ammonia Stress and Coccidiosis on Broiler Performance. Poult. Sci. 58(2): 465-468.

C-10. Groups of 80 broiler chickens were exposed to 0, 50, or 100 ppm NH_3 from 28 to 53 days of age, and were orally inoculated with coccidia at 36 days of age. By day 42, the exposed groups had significantly decreased body weights, and the ammonia-exposed groups with coccidiosis infection had mild intestinal and airsac lesions, the birds exposed to 50 ppm NH_3 the most affected.

3-185 Quarles, C. L., and H. F. Kling. 1974. Evaluation of Ammonia and Infectious Bronchitis Vaccination Stress on Broiler Performance and Carcass Quality. Poult. Sci. 53:1592-1596.

C-9. A total of 320 broiler chicks was exposed to 0, 25, or 50 ppm NH_3 from 4-8 weeks of age, and were vacinnated in that time. By week 8, broilers exposed to ammonia had significantly reduced body weights and feed efficiencies. At weeks 6 and 8, broilers had a severe airsacculitis condition.

3-152 Reece, F. N., B. D. Lott, and J. W. Deaton. 1980. Ammonia in the Atmosphere During Brooding Affects Performance of Broiler Chickens. Poult. Sci. 59(3):486-488.

C-10. Less useful model than the swine reports. Eighty chicks were exposed to 50, 100, or 200 ppm for 28 days, which caused decreased body weight, with recovery to normal weight within 8 days after exposure stopped for the lower levels. 100 and 200 ppm caused considerable mortality, but authors suggest that low levels are more damaging to performance on a per-unit-of-ammonia basis.

3-199 Renne, R. A., and K. E. McDonald. 1979. Toxic Effects of Geothermal Effluents: Acute and Subacute Inhalation Toxicology of Hydrogen

Sulfide and Ammonia in Rodents. In: Pac. Northwest Lab. Annu. Rep. 1979 DOE. Assist. Sec. Environ. Pt. 1: Biomedical Science. p. 275.

D--. Part of an annual report, so this reference is just a summary. An initial 7-day exposure to 250 ppm NH_3 caused no significant changes in rats or guinea pigs. A subsequent 7-day exposure to the same level caused a mild increase in the incidence of acute respiratory tract inflammatory lesions in guinea pigs. Subsequent exposure instead to 220 ppm H_2S caused mild interstitial pneumonitis. Mild chronic nephritis was also present in both groups.

3-155 Richard, D., G. Bouley, and C. Boudene. 1978a. Effects of Ammonia Gas Continuously Inhaled by Rats and Mice. Bull. Eur. Physiopathol. Respir. 14(5):573-582.

B-11. A good study, the only limit being the high NH_3 level used (500 ppm). Rats seemed able to adapt to this exposure. Mice were more susceptible to airborne infection after 7-d exposure.

3-154 Richard, D., J. M. Jouany, and C. Boudene. 1978b. Toxicité aiguë par voie aérienne du gaz ammoniac chez le lapin [Acute Inhalation Toxicity of Ammonia in Rabbits]. C. R. Acad. Sci. [D] (Paris). 287(4):375-378.

B-10. Acute exposure of rabbits to very high levels (1,000-20,000 ppm) by artificial ventilation (and so of limited use in this task) caused pulmonary edema and cardiovascular dysfunction.

3-157 Richardson, P. S., R. J. Phipps, K. Balfre, and R. L. Hall. 1978. The Role of Mediators, Irritants and Allergens in Causing Mucin Secretion from the Trachea. Ciba Found. Symp. 54:111-131.

C-6. An anaesthetized cat with 3 cannulae inserted into the trachea was exposed to NH_3 between 0.33 and 0.1%, directly into the lungs or into the trachea in different experiments. Coughing and rapid breathing occurred during lung exposure. Increased ^{35}S-labeled mucin output in the tracheal segment occurred during both exposures. This response was apparently both nervously mediated and partly due to local excitation.

3-217 Rumyantsev, G. I., T. A. Kozlova, I. K. Atyakina, E. P. Vishnevskaya, S. M. Novikov, V. A. Relsov, and L. A. Porokhova. 1980. Problems of Industrial Hygiene in Ammonium Sulfate Production. Gig. Sanit. No. 8:66-67 (Russ.).

D--. Workers were exposed to H_2SO_4, SO_2, NH_3, and dust, none exceeding the permissible limits. Heart-contraction frequency, arterial pressure, hemodynamic index, response time of erythemal-motor reactions, and other parameters indicate that the workers belong in the first and second category of severity.

3-160 Sadasivudu, B., and C. Radha Krishna Murthy. 1978. Effects of Ammonia on Monoamine Oxidase and Enzymes of GABA Metabolism in Mouse Brain. Arch. Int. Physiol. Biochim. 86(1):67-82.

D-8. Groups of six mice were exposed for 2 or 5 days to unknown but high concentrations of NH_3 vapor. After 2 days, monoamine oxidase activity had decreased in the brain stem and cerebellum, and increased in the cerebral cortex. On day 5, MAO activity had increased in the cerebellum, increased further in the cortex, and showed no change in the brain stem over day 2. Enzyme levels of GABA (gamma-aminobutyric acid) metabolism also fluctuated. The implications are discussed.

3-159 Sadasivudu, B., T. Indira Rao, and C. Radhakrishna Murthy. 1979. Chronic Metabolic Effects of Ammonia in Mouse Brain. Arch. Int. Physiol. Biochim. 87(5):871-875.

D-8. Methods the same as Sadasivudu and Radhakrishna Murthy (1978). Glutamate, aspartate, alanine, glutamine, GABA, RNA, protein, (Na^+ and K^+)-ATPase, and the enzymes in glutamate metabolism were measured in three regions of the brain (cerebellum, cerebral cortex, and brain stem). Results indicated that the brain was in a state of more depression and less of excitation.

3-076 Saifutdinov, M. M. (alternatively transliterated as Sayfutdinov) 1966. Maximum Permissible Concentration of Ammonia in the Atmosphere. Hyg. Sanit. 31(4-6): 171-176.

B-9. Rats exposed to low levels (0.2-20.0 mg/m^3) of NH_3 had shortened reflex response time and some altered blood and urine chemistry. Few actual data given.

3-216 Savina, V. P., L. N. Mukhamedieva, M. P. Kalandarova, V. V. Zhuravlev, K. N. Mikos, T. I. Kuznetsova, E. I. Nikitin, and K. V. Grishina. 1980. Evaluation of the Effect of Prolonged and Continuous Exposure of a Human Subject to Low (2 mg/m^3) Ammonia Concentrations under Conditions of an Airtight Chamber. Gig. Tr. Prof. Zabol. No. 12:63 (Russ.).

B-7. Exposure of humans to 2.16 mg NH_3/m^3 for 35 d caused a slight increase in O_2 consumption, increased NH_3 levels in the blood and exhaled breath and inhibition of the oxidative-reductive processes. All changes disappeared 3 d after exposure stopped.

3-078 Sayfutdinov, M. M. 1968. Experimental Data Proposed as a Basis for the Determination of Maximal Allowable Ammonia Concentration in Atmospheric Air. In: USSR Literature on Air Pollution and Related Occupational Diseases; A Survey. B. S. Levine (Translator). 17:67-76. PB180-522T, National Technical Information Service, U.S. Department of Commerce, Springfield, Virginia.

B-7. The effect of low NH_3 concentrations on the cerebral-cortical electrical activity of five people.

3-079 Sayfutdinov, M. M. 1973. Sanitary Characteristics of Ammonia and Validation of Its Maximum Permissible Concentration in Atmospheric Air. In: American Institute of Crop Ecology (AICE) Survey of USSR Air Pollution Literature. Vol. 19. M. Y. Nuttonson, ed., Silver Spring, Maryland. pp. 58-61.

C-4. A very brief review of several studies by the author, abstracted elsewhere in this bibliography.

3-080 Schmidt, F. C., and D. C. Vallencourt. 1948. Changes in the Blood Following Exposure to Gaseous Ammonia. Science. 108:555-556.

B-8. The effects on blood pressure and concentrations of non-protein nitrogen, urea, and creatinine in the blood from breathing 530-560 ppm NH_3 by one human male for 4 h are described.

3-081 Sestier, F., J. Bernier, and R. Charbonneau. 1969. Bronchopneumopathie d'origine toxique par inhalation de vapeurs ammoniacales. Á propos d'un cas [A Case History of Bronchopneumopathy Caused by the Inhalation of Ammonia Vapors]. Union Med. Can. 98:1903-1910.

B-8. A young woman accidentally exposed to NH_3 when refrigerator tubing ruptured suffered extensive and long-term respiratory complications.

3-082 Shimkin, M. B., A. A. de Lorimier, J. R. Mitchell, and T. P. Burroughs. 1954. Appearance of Carcinoma Following Single Exposure to a Refrigeration Ammonia-Oil Mixture. Report of a Case and Discussion of the Role of Cocarcinogenesis. A.M.A. Arch. Ind. Hyg. Occup. Med. 9:186-193.

C-7. Cannot separate effects of oil (and its contaminants); need more case studies (ammonia and interactions). Tannic acid is as likely a co-carcinogen as NH_3 in this case (if not more so--repeated use, known tissue reactions).

3-083 Silver, S. D., and F. P. McGrath. 1948. A Comparison of Acute Toxicities of Ethylene Imine and Ammonia to Mice. J. Ind. Hyg. Toxicol. 30:7-9.

C-11. Exposure of mice for 10 min to very high levels of NH_3 yielded an LD_{50} of 7.06 ± 0.32 mg/L. Practically all deaths occurred during actual exposure, with rapid recovery after exposure of those who did not die.

3-084 Silverman, L., and J. L. Whittenberger. 1949. Blood Changes Due to Ammonia Inhalation? Science (Comments and Communic.). 109:121-122.

C-8. Comments on the study by Schmidt and Vallencourt (1948), and comparisons to the study by Silverman et al. (1949) [3-085].

3-085 Silverman, L., J. L. Whittenberger, and J. Muller. 1949. Physiological Response of Man to Ammonia in Low Concentrations. J. Ind. Hyg. Toxicol. 31:74-78.

A-11. Human males were experimentally exposed to 500 ppm NH_3 in air, which is high by pollution standards.

3-200 Sim, M., and R. E. Pattle. 1957. Effect of Possible Smog Irritants on Human Subjects. J. Am. Med. Assoc. 165:1908-1913.

D-7. The effects of sulfuric acid mist exposure for 50 min on an unknown number of men were alleviated when NH_3 was introduced in "sufficient" concentration.

3-086 Sinitsyna, E. L. 1965. Investigations into Certain Aspects of the Health of People Working in the Main Shops of Tanneries. Hyg. Sanit. 30(4-6):336-340.

D-6. Variations in the diurnal curves of tannery employees exposed to unknown, but probably low, levels of NH_3.

3-087 Sloan, C. H., and G. P. Morie. 1974. Determinations of Ammonia in Tobacco and Tobacco Smoke with an Ammonia Electrode. Anal. Chim. Acta. 69:243-247.

D-12. The amounts of NH_3 in smoke per cigarette (smoked down to a 27-mm butt) found according to tobacco and/or filter type were: dark tobacco, 153 μg; burley, 102 μg; flue-cured, 51 μg; nonfilter, blended tobacco, 67 μg; and filtered, blended tobacco, 36 μg.

3-088 Slot, G. M. J. 1938. Ammonia Gas Burns. An Account of Six Cases. Lancet. 2:1356-1357.

B-7. Six cases of ammonia burns and respiratory symptoms are described. Exposure was due to explosion of a pipe conveying ammonia gas in an ice cream factory.

3-090 Smirnova, N. A., and N. P. Granik. 1971. Ob Otdalennykh Posledstviyakh Professional'nykh Ostrykh Porazhenii Dykhatel'nykh Putei Razdrazhayushchimi Gazami [Late After-Effects of Occupational Acute Damage to Respiratory Passages by Irritating Gases]. Gig. Tr. Prof. Zabol. 15(11):16-19.

D--. Of 88 cases of occupational poisoning by irritating gases, only two had been affected by NH_3. These two poisonings were accompanied by edema of the mucous membrane of the pharynx with subsequent necrosis of the tonsils. In one of the cases, subatrophic pharyngo-laryngitis was late after-effect.

3-162 Sobonya, R. 1977. Fatal Anhydrous Ammonia Inhalation. Hum. Pathol. 8(3):293-299.

C-10. Morphologic and morphometric pulmonary alterations in a male patient with anhydrous NH_3 inhalation (accidental, high levels) dying 2 mo after exposure are described. Terminal nocardial (microbially caused pulmonary infection) pneumonia, cylindrical bronchiectasis of the lower lobes, and fibrous obliteration of the small airways were found. The latter may be responsible for the chronic obstructive lung disease in the survivors of an episode of NH_3 inhalation.

3-108 Stolpe, J., and R. Sedlag. 1976. Die Einzel- und Komplexwirkung von Ammoniak und Schwefelwasserstoff in der Luft a uf kleine Versuchestiere (Ratten) bei unterschiedlichen Umweltbedingungen. 1. Meitteilung: Die Wirkung von Ammoniak [Single and Complex Effect of Ammonia and Hydrogen Sulfide in the Air on Small Laboratory Animals (Rats) Under Various Environmental Conditions. 1. Effect of Ammonia]. Arch. Exp. Veterinaermed. 30(4):533-539.

B-11. Little effect was seen on rats exposed to 30 ppm NH_3. Good controls, but fairly small sample sizes in all groups.

3-092 Stombaugh, D. P., H. S. Teague, and W. L. Roller. 1969. Effects of Atmospheric Ammonia on the Pig. J. Anim. Sci. 28:844-847.

B-11. Good dose range, to 10 ppm. Exposure of pigs to dose range (10-150 ppm) which included levels useful for pollution studies. Little respiratory effect seen, particularly after 2 weeks, but adverse effect on feed consumption.

3-218 Stupfel, M., F. Romary, M. Magnier, and J. Polianski. 1971. Comparative Acute Toxicity, in Male and Female Mice, of Some Atmospheric Pollutants: Automobile Exhaust, NO_x, SO_2, O_3, NH_3, and CO. C. R. Soc. Biol. 165:1869-1872 (Fre).

D--. Mice were exposed to 12,000 ppm NH_3 for 20 min or 11,000 ppm NH_3 for 40 min, with overall mortalities of 71 and 54%, respectively. Differences were reported in the mortality rates of the sexes, those for males being greater.

3-209 Taiganides, E., and R. K. White. 1969. The Menace of Noxious Gases in Animal Units. Trans. ASAE (Am. Soc. Agric. Eng.). 12(3):359-362.

D--. A review of the occurrence of H_2S, NH_3, CO_2, and CH_4 in animal units, and their toxicities to different species. Includes a discussion of potentially lethal situations and preventive measures.

3-163 Trubitskaya, G. P., A. N. Boiko, R. F. Komarova, and N. P. Cherednichenko. 1978. Vozdeistsvie Khimicheskogo Faktora Maloi Intensivnosti na Organizm Detei v Usloviyakh Primeneniya Polimernykh Materialov v Stroitel'stve [Effect of a Low-Intensity Chemical Factor on Children Under Conditions of the Use of Polymeric Materials in Construction]. Pediatriya (Moscow). No. 8:26-29.

D-7. Four hundred and three children (2- to 7-y-old) in three different schools were studied for possible effects of air pollutants from the use of polymeric construction materials. Test groups (with 0.124 or 0.134 mg NH_3/m^3, trace or 0.124 mg phthalates per cubic meter, and 0.010 or 0.017 mg $HCHO/m^3$) showed increased immunobiologic changes and allergic-type reactions compared to the control group (0.92 mg NH_3/m^3, trace of phthalates, and 0.010 mg $HCHO/m^3$).

3-164 Ulfvarson, U. 1978. Chemical Hazards in the Paint Industry. Proc. Int. Symp. Control Air Pollut. Work. Environ. Part 2:62-75.

D-8. Measurements of dust, NH_3, and solvent levels in 10 factories of the Swedish paint industry indicated that all were generally above hygienic health standards. Twenty-six percent of the 244 employees (in nine different job categories) interviewed had some skin changes on their hands or under their arms. However, NH_3 concentrations were poorly presented, not correlated with types of jobs and skin changes, and the employees washed their hands with solvents or solvent-containing soaps.

5-424 Urban, C. M., and R. J. Garbe. 1980. Exhaust Emissions from Malfunctioning Three-Way Catalyst-Equipped Automobiles. S.A.E. Tech. Pap. Ser. 1980, 80051. 11 pp.

C--. Maximum emission rates (mg/m^3) in four malfunctioning, three-way catalyst-equipped automobiles:

NH_3	254
CN	67
H_2S	8
HCHO	3

3-094 USSR State Committee of the Ministers for Construction. 1972. Sanitarnyye Normy Proyektirovaniya Promyshlennykh Predpriyatiy [Sanitary Norms for Industrial Enterprise Design]. Izdatel'stvo Literatury po Stroitel'stvu [Publishing House of Literature on Construction]. Moscow. 96 pp.

C--. In the USSR, the MAC for NH_3 in workplaces was 20 mg/m^3 and in populated places was 0.2 mg/m^3 (one-time and avg.).

3-189 Valentine, H. 1964. A Study of the Effect of Different Ventilation Rates on the Ammonia Concentrations in the Atmosphere of Broiler Houses. Br. Poul. Sci. 5:149-159.

B-10. The effect of increased NH_3 levels on chickens, and some useful information on relative humidity and NH_3 concentration.

5-413 Van Gemert, L. J., and A. H. Nettenbreijer. 1977. Compilation of Odour Threshold Values in Air and Water. National Institute for Water Supply. Leidschendam, The Netherlands, and Central Institute for Nutrition and Food Research, TNO, Zeist, The Netherlands.

A--. Compilation of odor threshold values reported by different researchers, for many compounds, including:

Ammonia	0.03-37 mg/m^3
HCN	< 1.1-6 mg/m^3
H_2S	0.001-2 mg/m^3
HCHO	0.033-2.2 mg/m^3
Methanol	4.3-11,700 mg/m^3
Acrolein	0.05-4.1 mg/m^3

3-165 Verberk, M. M. 1977. Effects of Ammonia in Volunteers. Int. Arch. Occup. Environ. Health. 39(2):73-82.

A-13. "Experts" (members of the Subcommittee on Toxicology, familiar with the literature on NH_3) and "nonexperts" (nonscience students) were exposed to NH_3 with no change in lung function tests, and varying subjective responses. No actual lung function data given. Authors felt that results justified Public Emergency Limits as high as 100, 75, and 50 ppm for, respectively, 10, 30, and 60 min.

3-097 Vigliani, E. C., and N. Zurlo. 1955. Erfahrungen der Clinica del Lavoro mit einigen maximalen Arbeitsplatzkonzentrationen (MAK) von Industriegiften [Experience of the Labor Clinic with Several Maximal Workplace Concentrations (MAC) of Industrial Poisons]. Arch. Gewerbepathol. Gewerbehyg. 13:528-534.

D--. Review. The maximum allowable concentration was 50 ppm NH_3 rather than the 100 ppm set by the ACGIH.

3-098 Vikshraitis, Ch. Yu., and N. P. Motejunene. 1972. Kol'poskopicheskoe Vyyavlenie Predrakasheiki Matki u Zhenshchin, Razbotayushchikh s Nekotorymi Promyshlennymi Yadami [Colposcopic Recognition of the Cervical Precancer in Females Working with Certain Industrial Poisons]. Vopr. Onkol. 18(12):41-45.

D--. Three hundred ninety-three female pharmaceutical workers occupationally exposed to a complex air mixture including 7.2-136.2 mg NH_3/m^3 had increased percentage of precancerous lesions of the cervix compared to the control group.

3-166 Vilisov, B. A., N. S. Irger, L. M. Kremko, Z. N. Pavlyutina, I. G. Tseluiko, Y. S. Danishevich, and S. S. Khudnitskii. 1980. Gigienicheskaya Otsenka Nekotorykh Sinteticheskikh Smol i Ikh Vliyanie na Zabolevaemost' Rabochikh Liteinykh Tsekhov [Hygienic Evaluation of Some Synthetic Resins and their Effect on the Health of Molding Department Workers]. Zdravookhr. Beloruss. No. 1:31-34.

D-7. Foundry core workers usng phenol-formaldehyde copolymer, urea-formaldehyde, and furan resins suffered a higher rate of disorders of the skin, liver, kidney and respiratory organs compared to workers involved in machine building. Metal casting workers using these resins were ill about half as often and half as long as the core

makers. The casters were more exposed to phenol, NH_3, CO, and HCN than the core makers, who were more exposed to HCHO, methanol, and furyl alcohol.

3-168 Visek, W. J. , S. K. Clinton, and C. R. Truex. 1978. Nutrition and Experimental Carcinogenesis. Cornell Vet. 68(1):3-39.

D--. The ammonia ultimately produced in the alimentary tract from ingested protein may be implicated in colon carcinogenesis.

3-099 Voisin, C., F. Guerrin, H. Robin, D. Furon, and F. Wattel. 1970. Sequelles fonctionelles respiratoires des intoxications par l'ammoniac (A propos de 8 observations) [Respiratory Functional Sequelae of Ammonia Poisoning]. Poumon Coeur 26:1079-95; copyrighted English translation provided by the National Institute for Occupational Safety and Health, Rockville, Maryland.

B-11. A good study for late effects. The pulmonary functional changes of eight victims of accidental NH_3 exposures, with different degrees of severity of the initial acute phase, were followed for 1-5 y after exposure.

3-100 Walton, M. 1973. Industrial Ammonia Gassing. Brit. J. Ind. Med. 30:78-86.

B-11. Seven cases of ammonia gassing with 5-y follow-up for six survivors and post mortem findings for the fatal case are described. NB: Interaction with smoking described. No quantitative exposure data.

3-101 Weatherby, J. H. 1952. Chronic Toxicity of Ammonia Fumes by Inhalation. Proc. Soc. Exp. Biol. Med. 81:300-301.

D-7. Twelve male guinea pigs were exposed to a variable NH_3 concentration (140-200 ppm), with 170 ppm the desired concentration, in repeated daily doses for 6-18 weeks. Only in the 18-week exposure group were mild, though definite, changes seen in the spleens, kidneys, livers, and adrenal glands. No consistent changes were found in hearts, lungs, stomachs, or small intestines.

3-102 Weedon, F. R., A. Hartzell, and C. Setterstrom. 1940. Toxicity of Ammonia, Chlorine, Hydrogen Cyanide, Hydrogen Sulphide, and Sulphur Dioxide Gases. V. Animals. Contrib. Boyce Thompson Inst. 11:365-385.

C-8. A group of eight rats and four mice was exposed to 1,000 ppm NH_3 for 16 h, and autopsies were performed 5 months later on two rats. A few slight eye and respiratory symptoms were observed during exposure, and there were no findings on autopsy.

3-170 Wood, R. W. 1979. Behavioral Evaluation of Sensory Irritation Evoked by Ammonia. Toxicol. Appl. Pharmacol. 50(1):157-162.

D-11. Behavioral response of six mice to 0.05-0.2% (500-2,000 ppm) NH_3 for a maximum of 60 s. The duration of exposure decreased and the percentage of ammonia deliveries terminated by the trained mice in response to the NH_3 exposure increased with increasing NH_3 concentration.

3-105 Yelfimova, Ye. V., N. S. Yevseyenko, Ya. K. Yushko, N. N. Pushkina, S. K. Nenosheva, and G. N. Kuznetsova. 1971. Sanitary Evaluation of Air Pollution in Areas Around Ferrous Metallurgical Plants. In: American Institute of Crop Ecology (AICE) Survey of U.S.S.R. Air Pollution Literature. Vol. 7. M. Y. Nutlonson, ed., Silver Spring, Maryland. pp. 22-26.

D-6. Ammonia (0.3 to 8.0 mg/m^3) was only a minor component of gases emitted from the metallurgical plants. Children living within 1,000 m of the plant showed more upper respiratory, somatic, and infectious diseases than did the children living 12,000 m from plant No. 1, which caused heavy SO_2 pollution in its environs.